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The Effect of Chemical Competition on Thermodynamics of Bacterial Adsorption

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THE EFFECT OF CHEMICAL COMPETITION ON THERMODYNAMICS OF BACTERIAL ADSORPTION

by

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ABSTRACT

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on Thermodynamics of

Bacterial Adsorption

by

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The objective of this investigation was to study the effect of chemical competition on thermodynamics of bacterial adsorption. This was done using an experimental system consisting of Mendon silt loam soil as the adsorbent, Staphylococcus aureus as a common adsorbate and sodium chloride (NaCl), sodium lauryl sulfate (SLS), and peptone as competitive adsorbates.

The bacterial adsorption on soil both with and without chemical competition followed Langmuir type isotherms. From the equilibrium data, thermodynamic functions such as free energy, ΔF^{o}, enthalpy, ΔH^{o}, and entropy, ΔS^{o}, were calculated. Observed positive ΔH^{o} values indicated that the bacterial uptake in both noncompetitive and competitive environments is endothermic. Bacteria and soil both have a net negative charge. A positive ΔH^{o} value is attributed to

the repulsion between the bacteria and soil particles. For a non-competitive system, the observed ΔH^{o} value was 8.50 kcal-mole^{-1}. Relatively higher ΔH^{o} values were obtained in the presence of peptone and NaCl. These values were 24.0 kcal-mole^{-1} and 23.0 kcal-mole^{-1} for peptone and NaCl respectively, suggesting that the bacterial uptake is much more endothermic in the presence of these chemicals. The lower ΔH^{o} value (3.72 kcal-mole^{-1}) observed in the presence of SLS indicated that bacterial adsorption is relatively less endothermic in the presence of such a chemical.

In all the sorbent-sorbate systems studied, observed ΔS^{o} values were positive indicating that the bacteria are more disordered in the adsorbed phase than they are in the solution phase. Observed ΔF^{o} values for all the adsorption systems were negative, indicating that the bacterial adsorption in both competitive and noncompetitive environments is spontaneous.

(213 pages)

INTRODUCTION

In developing a rational theoretical framework to explain and predict bacterial adsorption, the competitive effect of chemicals may be important. This effect must be assessed: (1) for a comprehensive theoretical treatment, and (2) for the pragmatic end of estimating potential health hazards caused by bacterial contamination of groundwater. The study may also be useful in determining the role of adsorption in the removal of bacteria from polluted water in the presence of competitive chemicals whether the circumstance involves movement of bacteria through a natural soil system, a packed bed, or any other system involving suspended adsorbents. The problem can be best defined in terms of thermodynamics which will allow rational analysis of observations as well as provide a basis for synthesizing the solutions and methods of evaluation for any of a myriad of new situations.

At a time when effluent discharges are increasing, with commensurate discharges to groundwater (either inadvertant or due to recharge), the result is more extensive impacts on the groundwater system, due to expanding demands for new water supplies. Also soil systems are being used more extensively as a means of waste treatment (McGauhey and Krone, 1967). In addition to problems of

discrete inputs of wastewater into an aquifer system, there are questions concerning hazards from diffused surface sources, many of which are in proximity to groundwater supplies; these include septic tank leachates, hazards due to leaching through sanitary land fills and open dumps, and the effects of barnyards leachates on well systems. Recycle of waste waters from septic tanks to shallow wells in suburban areas has been well documented (Flynn, 1961). Also, recharge of aquifers with treated waste waters is being practiced currently and is being more extensively discussed. In all of these situations bacteria are inherently present; whether the chemicals commonly found in waste waters and leachates promote or inhibit the adsorbtion of bacteria is an unknown factor. Thermodynamics offers the most rational approach for resolving these questions.

Objective

The objective of this investigation is to delineate the thermodynamics of competitive adsorption. Specifically, the task is to:

(1) study the effect of several chemical species on adsorption isotherms of bacteria on soils

(2) evaluate the effect of chemical competition on bacterial adsorption in terms of enthalpy, entropy, and free energy

(3) incorporate the results of these studies into a predictive model.

Limitations

The limitations of this investigation are:

1. The effects of only representative chemicals (sodium lauryl sulfate, peptone, and sodium chloride) on the adsorption of viable bacteria of a particular species (*Staphylococcus aureus*) are studied.

2. The results imply specifically to certain textural class of soils (silt loam). However, these results could serve as guidelines to predict the adsorption magnitude in other types of soils.

3. The scope of this study is limited to the temperature range, 10C to 37C, because of the viability of test organism (*S. aureus*).

REVIEW OF LITERATURE

Groundwater Contamination

Before the 1950's, not much consideration was given in the literature to the problem of groundwater contamination, but during the fifties the American Water Works Association (1953, 1957) began to assess and monitor the situation, thus calling the attention to the magnitude of the problem. Later attention was focused by individual reports and in the sixties by a special symposium (Mallman and Mack, 1961). It is now recognized as a major hazard and more research effort is being put forth in this direction. Despite recent activities, the state of knowledge still falls far short of a close understanding of the phenomena. The primary focus herein is related to bacterial aspects of the problem.

The danger of contamination of wells by seepage has been recognized before the discovery of micro-organisms responsible for the disease. In 1854 in London (Prescott and Harwood, 1935), Dr. John Snow established that victims of cholera epidemic had used the water from a drinking water well which was found to be contaminated by seepage. Later, in 1872 (Prescott and Harwood, 1935) in Switzerland, a brook was contaminated by waste from typhoid patients in the neighboring valley separated by a high hill,

indicating the movement of typhoid organisms through the high hill. Also, Ditthorn and Leurssen (1909) reported the movement of bacteria through soil in Germany.

In the early twenties W. L. Mallman (unpublished data) conducted a study in order to detect the effect of septic tank field in contaminating a well located approximately 30 feet away. A gallon of S. marcescens culture was added to the siphon chamber of a septic tank. Two small test wells were drilled at 10-feet intervals between the septic tank and the well. The S. marcescens was detected in the test well adjacent to the septic tank in two days, in the second test well in three days, and in the study well in ten days. During this study the source of pollution was well established.

Stiles and Chrohurst (1923) studied the migration of bacterial pollutants from sewage flooded trenches. They demonstrated that the bacterial pollution was largely at the interface between the groundwater surface and the capillary water zone. Bacteria traveled 232 feet, whereas fluorescent dye traveled 450 feet. Pollution traveled in the direction of the groundwater flow.

Caldwell and Parr (1937) investigated the migration of bacteria as measured by coliform organisms from the bored-hole latrine that penetrated below the water table. Initially coliform organisms traveled 15 feet in 3 days. After 3 months of continued use of latrine, 90 percent recovery was made at 15 feet, 40 percent at 25 feet, and

only an occasional positive sample at 35 feet. Caldwell (1938) made a study of pit latrines located in an area where an impervious stratum underlies the groundwater. Under these conditions coliform organisms traveled 40 feet in less than 3.5 days.

A study was made by Baar (1957) in the Netherlands concerning the travel of micro-organisms in sandy soils with heavy pollution from pit latrines. In dry soil coliform organisms penetrated to a depth of 10 feet.

Bacteria migrate in the direction of groundwater flow. Because of adsorption on soil particles and the straining action of the substratum, travel is limited in distance, and this distance is determined in part by the rate of groundwater flow and the particle size of the substrate. The kind and amount of suspended material in the recharge water will determine the travel distance by forming a filtering barrier at the point of entry. Besides bacteria, viruses can also be carried through groundwaters for considerable distances from points of contamination. Viruses are also found in sewage.

Among chemical contaminants the most commonly reported inorganic contaminants are salt water, oil field brines and sodium chloride with an occasional report of specific toxic agents such as fluoride, chromium, and nitrate. In many states the two most important causes of extensive inorganic contamination are sea water intrusion and deep percolation from irrigated agriculture.

The types of organic chemical contaminants reported to have been responsible for one or more incidents of contamination are ABS (alkyl benzene sulfonate), cresols, 2,4-D, dichlorophenol, gasoline, and hexachlorocyclo-hexane. Although our present information on the persistence of organic contaminants in groundwater is limited, indications are that once such material has reached the water table they may persist for longer periods of time. ABS is difficult to degrade biologically and is expected to persist in groundwaters.

ABS is introduced as part of the common products used in household laundering and cleaning. ABS contamination occurs in densely populated and fast growing areas on septic tank systems (Flynn, 1961). The synthetic detergent problem becomes more severe with the passage of time. The ABS is usually slow in polluting the well, but once the breakthrough is accomplished the ABS content of the water increases rapidly. What makes it more serious is that groundwater pollution is of long duration even though the source of pollution is removed. Synthetic detergents marketed today contain a variety of ingredients including surface active agents, phosphate builders and miscellaneous builders. The surface active agents are commonly anionic compounds and a class of compound called alkyl benzene

sulfonate (ABS). These surfactants in concentration greater than 0.5 mg/l cause the foam in water. Toxicity studies on humans and animals indicate that the toxicity of ABS is so low as to cause no effect in man at concentrations likely to be encountered in drinking water.

A literature review by Walton (1960) revealed that a distance traveled by ABS is short in some instances and quite far in some other instances. ABS traveled about 100 feet in some cases and about 1000 feet in others. The source of pollution was through household sewage disposal in the first case, and the municipal disposal in the other.

The above studies show that the chemicals travel a greater distance than the bacteria under the same conditions, which in other words means that the bacteria are retained more efficiently than the chemicals by the soil.

Whether a chemical species acts to promote or inhibit bacterial adsorption is a question of practical significance due to the diverse and heterogenous nature of waste waters.

Removal of Contaminants

Capcity to adsorb chemicals is strongly developed in clay minerals, but many other rock minerals have at least small capacity to adsorb cations from the solution. Productive aquifers generally

contain little clay present as a thin coating on sand grains and larger rock particles, enough to give considerable adsorption capacity. The strength of the forces holding the ions is greater in divalent ions than the monovalents. Also the ions with the smaller radii are held more tightly than the ions with larger radii.

The mechanism mostly responsible for the retention of anionic surfactants is physical adsorption on the soil. Soils, particularly the clay fraction, exhibit some cation exchange capacity; their anion exchange capacity is almost nonexistent. The ABS is soluble at low concentrations found in waste water, particularly when diluted by groundwater. Adsorption, however, might account for considerably more retentive capacity than the pore volume of the formation in view of the very low concentration of these substances in the transporting water.

In 1959, Renn and Berada investigated the use of different adsorbents for the removal of ABS from water supplies. These studies showed that suspended silt could adsorb 20 to 50 mg of ABS per gram of silt. For clay, talc, silica, and calcium carbonate, the adsorption was in the magnitude of 1 mg of ABS per gram of the material.

Undoubtedly, the adsorption on the surface of the soil particles is an important mechanism in retarding the movement

of ABS, but under some conditions development of zoogleal slime on the soil particles may cause further loss of ABS. The large surface area provided by microbial cells may well offer considerable adsorptive capacity for ABS. In addition it is known that there is some bacterial decomposition of ABS. Many investigators (McGauhey and Klein, 1959; Sawyer, 1958; McKinney and Symons, 1959) studied the biological degradation of ABS and they have shown that it is slow.

The physical adsorption of ABS on Ottawa sand is very much lower than on finer earth materials (Ewing, Lefke, and Banerji, 1961). The adsorption of ABS on sand is time dependent. In batch experiment where intimate contact between the sand and the ABS is afforded, at least one hour is required for equilibrium. The low adsorption obtained in column experiment may be due to failure to saturate all the surface of sand.

From the comparison of retention of ABS on two columns, one with and one without biological growth on earth material, the one with biological growth enhances the adsorption. With 50 mg/l ABS in feed solution, seven times as much ABS was retained on the solid phase of the column in which biological slime had been developed. It has not been fully determined to what extent retention was due to adsorption of the large surface area afforded by these bacterial cells, but it appears that this is an important phenomenon. However,

it is concluded that the adsorption on biological slime is one mechanism that retards the movement of ABS in a septic tank drain field.

Bacteria can be removed from recharge water in an aquifer by filtration. Adsorption is felt to be a major mechanism in this process. Factors such as deactivation and entrapment may also be a mechanism of bacterial removal.

Studies (McGauhey and Krone, 1967) show that the soil system has a great ability to remove bacteria and viruses but is somewhat selective in its effect on chemicals. They also show the importance of keeping waste water in contact with the biological system until biochemical reactions are complete. Otherwise unstable and objectionable intermediate products of degradation may escape beyond the treatment system in the soil and contaminate groundwater.

Viruses are removed by soil systems, principally by adsorption, as effectively as are bacteria (McGauhey and Krone, 1967). It may be concluded that biological antagonism and physical removal of bacterial and viral cells characterize the change in biological quality of water percolating through a soil system and that the system is quite an efficient device for removing such cells.

Adsorption

Adsorption of certain chemicals on clay minerals has been well established. Brooks (1955) determined the complete nitrogen adsorption isotherms for selected representative samples of kaolinite, illite, halloysite, pyrophyllite, and montmorillonite at various temperatures between 25C and 1000C. The clays such as montmorillonite and illite which were characterized by appreciable cation exchange capacity and comparatively small particle size showed marked nitrogen adsorption. In the montmorillonite the nature of exchangeable cation, whether sodium or calcium,had an appreciable effect on the nitrogen adsorption capacity. The clays such as kaolinite and pyrophyllite which are characterized by small cation exchange capacity and comparatively large particle size showed very little nitrogen adsorption capacity.

In 1959, Jurinak and Volman studied the adsorption of N-butane by ca-kaolinite and ca-montmorillonite, to determine the nature of differences that occur during the adsorption of nonpolar molecules by clay minerals. A greater amount of N-butane was adsorbed by montmorillonite than kaolinite. This was attributed to the porous and nonporous nature of montmorillonite and kaolinite respectively. Adsorption of nitrogen on these clay minerals followed an isotherm.

Brooks (1965) measured the water vapor and benzene adsorption isotherms over the temperature range from 25C to 55C, on sodium, calcium and pyridinium montmorillonite. The hydrophilic cations such as sodium and calcium promoted the adsorption of a polar adsorbate like water whereas an oleophilic cation such as pyridinium promoted the adsorption of lower polar compound like benzene.

Mclean, Lakshmanan, and Miller (1969) studied the relative adsorption of strontium and calcium on soil samples from different horizons. Results indicated marked preferential adsorption of calcium in the upper horizon (AP) soil sample, small preferential strontium adsorption in B_2 horizon, and equal adsorption of calcium and strontium in the C horizon sample.

Adsorption of water vapor on Millville loam soil was studied in an air free system (Cary, Kohl, and Taylor, 1964). Adsorption of water vapor at the very low relative humidities appeared to increase with increasing temperature. An average integral entropy of the adsorbed film was found to be greater than that of liquid water. This increased entropy was attributed to ionic hydration and to clay swelling.

In 1969, Sharma, Uehara, and Mann determined water vapor adsorption isotherms for two clayey soils, at 25C and 30C. Taking liquid water as a standard state both integral and differential thermodynamic quantities viz. enthalpy, entropy, and free energy were calculated. Integral entropies were taken as a measure of

adsorbed-water molecular disordering. Results strongly suggested that adsorbed water was more disordered than the liquid water. Comparatively high numerical values for heat of adsorption, integral and differential entropy and spreading pressure as well as the shape of the isotherms, all suggested that chemisorption plays an important role in adsorption process.

Prout in 1957 studied the adsorption of strontium on soil. Adsorption was found to be dependent on the strontium concentration and on the pH of the solution. Strontium adsorption was greatly inhibited by the hydrogen ion. Adsorption was negligible at pH of 2. From pH 2 to 4 the increase in adsorption was marked. Maximum strontium adsorption occurred at pH of 7. Reduced adsorption above pH 8 was mainly due to the competitive effect of sodium ion present as a result of adjustment of the pH with sodium hydroxide. The effect of hydrogen, sodium, and calcium ions on the adsorption of strontium was also investigated. Variations in pH were obtained by adding nitric acid, sodium hydroxide, ammonium hydroxide, or calcium hydroxide to the soil mixture prior to the equilibrium. Results of these experiments illustrated that for the maximum strontium adsorption to be achieved the waste solution should be neutralized with sodium hydroxide in preference to ammonium hydroxide. This suggests that ammonium ion competes better than sodium ion with strontium for adsorption. Aluminum ion was also found to compete with strontium for adsorption (Prout, 1957).

Adsorption of E. coli bacteriophage T_4 on activated carbon was studied (Cookson and North, 1967) in an agitated solution containing virus and carbon under controlled conditions of temperature, ionic strength, ionic composition, and reactant concentrations. They described the kinetics of bacteriophage T_4 adsorption on activated carbon by a reversible second order equation, first order with respect to both virus and carbon concentration. The reversible nature of adsorption was demonstrated by greater desorption in the presence of competitive adsorbate tryptone. Adsorption was unimolecular with very inefficient use of the available carbon surface area and was of physical nature and independent of temperature. The virus was probably completely excluded from pores because of its size. The virus was not inactivated by adsorption.

Adsorption of bacteriophage T_4 on activated carbon was represented by the Langmuir isotherm which suggests the formation of unimolecular layer. The maximum coverage of the adsorbent was estimated at 18 percent. This small surface coverage not only confirms single layer adsorption but also indicates that pore areas are not utilized. Application of Langmuir isotherm yielded a carbon capacity of 1.6×10^9 sites per mg.

In the beginning of 1969, Cookson published a paper proposing a possible mechanism of virus adsorption on activated carbon. According to this study, the following important conclusions can be drawn.

1. Sites on activated carbon that adsorb bacteriophage T_4 are probably a carboxyl group or lactone. Thus adsorption on activated carbon can be completely blocked by esterifying these groups.

2. It can be proposed that amino groups on virus adsorb to carboxyl groups on carbon by electrostatic attraction. The pH range of strong adsorption rules out participation by ionized forms of sulfhydryl, guanidino and phenolic groups in the electrostatic binding. Ionized imidazolyl groups are probably too few to be significant.

3. As pH decreases from the optimum of 7, adsorption rate decreases, probably as a result of viral tail fibers being attached to the tail sheath, making them unavailable for attachment to carbon sites.

4. At pH values higher than optimum the tail fibers of bacteriophage T_4 are extended. The observed decrease in adsorption rate presumably resulted from an increase in negative charge on the virus particles and carbon surface, causing greater repulsive forces between viruses and carbon particles. The collision frequency is thus reduced.

Electrostatic binding of virus and carbon and designation of viral tail fibers as the adsorbing units are received from the effect of ionic strength on adsorption. With increasing ionic strength, adsorption is aided, as like charges on the virus and carbon particles are masked,

at the same time repulsive forces between the viral tail sheath are reduced. With increasing ionic strength more and more tail fibers adsorb on the tail sheath. Although high ionic strength causes a maximum collision frequency between virus and carbon particles, the adsorbing tail fibers become less available. These mechanisms are supported by equilibrium studies at high and low ionic strengths.

In 1968, Drewry and Eliassen published the paper on virus movement in groundwater. According to this study, the following facts may be noted.

1. Virus retention by soils is an adsorption process and is affected to a greater or lesser extent by many environmental conditions. The adsorption process observed in this study is characterized by linear adsorption isotherms.

2. Virus adsorption by soils is greatly affected by the pH of the water-soil system. This effect is due primarily to the amphoteric nature of protein shell of the virus particles. At lower pH values, below 7.0 to 7.5, virus adsorption is rapid and effective to a high degree. Higher pH values considerably decrease the effectiveness of virus adsorption by soils because of increased ionization of the carboxyl groups of the virus protein and increasing negative charge on the soil particles.

3. Virus adsorption by some soils is greatly enhanced by increasing the cation concentration of the liquid phase of a soil-water system.

The cations present in the water neutralize or reduce the repulsive electrostatic potential (the negative charge) on either the virus particles or the soil particles or both and allow adsorption to proceed.

4. In general, adsorption of virus particles by soils increases with increasing clay content, silt content ion-exchange capacity, and glycerol retention capacity. However, a soil could be ranked lower than other soils in any one or all of the above mentioned properties and still rank highest in virus-adsorption ability.

Above review indicates that adsorption of both chemicals and viruses on soil follow an isotherm. Based on this review, it was hypothesized that bacteria would also be adsorbed on soil in accordance with an isotherm.

THEORY OF ADSORPTION

Adsorption

In its most general sense adsorption can be described as accumulation at interfaces of materials usually in different phases and it can include particles that migrate into the sorbent. Affinity of dissolved or suspended material (sorbate) for particles in the soil (sorbent) results from the attractions of an unlike electrostatic charge (ion exchange for example), Van der Waal's attraction (all matter at close proximity), and valence bonds. The fourth factor that contributes to the affinity between sorbate and sorbent is the solubility of sorbate in the surrounding fluid. If the molecule is hydrophobic, for example, it will try to leave the water solution and will accumulate at any surface not repulsive to it.

Adsorption Isotherms

It is hypothesized that the bacterial adsorption reaction is similar to a normal chemical reaction and the equilibrium for that reaction can be described in the normal manner involving an equilibrium constant. As will be shown later, this equilibrium constant is actually the Langmuir isotherm constant and the equilibrium behavior of the reaction can be described in terms of a Langmuir isotherm. Although other isotherms such as Brunauer-Emmett-Teller (BET) isotherm, and

the Freundlich isotherm have been used, data herein fit the Langmuir, which is a special case of the BET (Laidler, 1965). The Freundlich isotherm, favorite of chemical engineers, is empirical and is not considered further. The Langmuir isotherm has been well established theoretically with reference to gas adsorption (Laidler, 1965). Laidler has described the use of the Langmuir isotherm for chemisorption. In 1967, Cookson and North demonstrated that the adsorption of viruses on activated carbon follows the Langmuir isotherm. Later in 1968, Drewry and Eliassen showed that adsorption of viruses on soils follows a linear isotherm. During this investigation it is hypothesized that bacteria are adsorbed on soil in accordance to the Langmuir isotherm.

Application of Langmuir Isotherm

Noncompetitive adsorption

Consider the following reaction wherein only bacteria are introduced into an adsorption system.

$$\text{soil} + \text{bacteria} \rightarrow \text{soil} \cdot \text{bacteria (complex)} \quad . \quad . \quad (1)$$

Designating the soil as X, C as the bacteria, and $\overline{X}$ as the soil · bacteria complex, Equation 1 is rewritten

$$X + C \rightarrow \overline{X} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

When the reaction is at equilibrium, all symbols are given an asterisk superscript to designate the equilibrium state (i.e. X^*, C^*, and $\bar{X}^*$). Equilibrium for this reaction can be expressed (Hendricks, Post, and Khairnar, 1969)

$$\alpha = \frac{\bar{X}^*}{X^* C^*} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

in which

α = the equilibrium constant

$\bar{X}^*$ = the number of bacterial cells adsorbed per gram of soil

C^* = the equilibrium concentration of bacteria in solution phase (cells/ml)

X^* = number of unoccupied adsorption sites per gram of soil

The maximum available adsorption sites are designated as X_m. The vacant sites, X^*, are then equal to $(X_m - \bar{X}^*)$. Making the substitution for X^* in Equation 3, the following expression can be obtained

$$\alpha = \frac{\bar{X}^*}{(X_m - \bar{X}^*) C^*} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Algebraically rearranging Equation 4 gives:

$$\frac{\overline{X}^*}{X_m} = \frac{\alpha C^*}{1 + \alpha C^*} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

which is the usual algebraic arrangement of the Langmuir isotherm.

Competitive adsorption

The Langmuir equation can also be applied to the case of competitive adsorption in which more than one sorbate compete for the same number of limited adsorption sites on a given sorbent. Consider the reaction for competitive adsorption wherein a chemical species, A, is competing with bacteria for sorption sites on soil.

$$\text{soil} + \text{bacteria} + A \rightarrow \text{soil} \cdot \text{bacteria} + \text{soil} \cdot A + \text{bacteria} \cdot A \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Designating A as a chemical species, $\overline{A}$ as soil·chemical complex, and $\overline{W}$ as bacteria · chemical complex, Equation 6 can be rewritten

$$X + C + A \rightarrow \overline{X} + \overline{A} + \overline{W} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

If it is assumed that there is no interaction between bacteria and the chemical species (experiments were conducted to verify this assumption), the last term on the right hand side of Equation 7 will drop out. Thus Equation 7 becomes

$$X + C + A \rightarrow \overline{X} + \overline{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

the equilibrium for this reaction is expressed as

$$\alpha' = \frac{\overline{X}^* \cdot \overline{A}^*}{X^* \cdot C^* \cdot A^*} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

where

α' = the equilibrium constant for reaction (Equation 8)

$\overline{A}^*$ = the equilibrium concentration of chemical species on solid phase (grams of chemical species adsorbed per gram of soil)

A^* = the equilibrium concentration of chemical species in the solution phase (grams of chemical species per liter of solution)

Since $X^* = (X_m - \overline{X}^* - \overline{A}^*)$, Equation 9 can be rewritten,

$$\alpha' = \frac{\overline{X}^* \cdot \overline{A}^*}{(X_m - \overline{X}^* - \overline{A}^*) C^* A^*} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

which is the equilibrium expression for the bacterial adsorption reaction in the presence of chemical competition (Equation 8).

The Langmuir isotherm for two sorbates (bacteria and chemical) competing for adsorption sites is expressed (Laidler, 1965, p. 262):

$$\frac{\overline{X}^*}{X_m} = \frac{\alpha C^*}{1 + \alpha C^* + \alpha' A^*} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

which represents the fraction of surface covered by bacterial cells. The fraction covered by chemical species can be expressed as

$$\frac{\overline{A}^*}{A_m} = \frac{\alpha' A^*}{1 + \alpha C^* + \alpha' A^*} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

in which

$\overline{A}^*$ = the amount of chemical adsorbed per gram of soil

A_m = the maximum value of $\overline{A}^*$

It is seen from Equations 11 and 12 that the fraction of the surface covered by bacteria is reduced if the concentration of the chemical competitor is increased. This is due to the fact that the bacterial cells and chemical molecules are competing with one another for the same limited number of surface sites and may be regarded in case as competitive adsorption.

Thermodynamics of Adsorption

Consider the reaction for noncompetitive adsorption wherein only one sorbate is involved in an adsorption system.

$$\text{soil} + \text{bacteria} \cdot H_2O \rightarrow \text{soil} \cdot \text{bacteria} + H_2O \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Designating Ch as bacteria · H_2O complex and W as a free water molecule, Equation 13 can be rewritten

$$X + C_h \rightarrow \overline{X} + W \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

and the equilibrium can be expressed as

$$\alpha = \frac{\overline{X}^* \cdot W^*}{X^* \cdot C_h^*} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

in which

C_h^* = the equilibrium concentration of bacteria · H_2O complex

W^* = the equilibrium concentration of H_2O in the solution

Other terms are already defined.

The equilibrium constant, α, is related to the free energy by the following equation (Appendix A):

$$\Delta F^o = - RT \ln \alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Differentiating with respect to temperature

$$- \frac{d(\Delta F^o)}{dT} = R \ln \alpha + RT \frac{d \ln \alpha}{dT} \quad . \quad . \quad . \quad . \quad (17)$$

When the reactants and products are in their standard state, the Gibb's-Helmholtz equation is (Appendix A):

$$\Delta F^o - \Delta H^o = T \frac{d(\Delta F^o)}{dT} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

Substituting Equation 18 in Equation 17, the following equation results:

$$- \Delta F^{o} + \Delta H^{o} = RT \ln \alpha + RT^{2} \frac{d \ln \alpha}{dT} \quad . \quad . \quad . \quad . \quad (19)$$

After substituting $\Delta F^{o} = - RT \ln \alpha$, in Equation 19 and rearranging, the following relation can be obtained:

$$\frac{d \ln \alpha}{dT} = - \frac{\Delta H^{o}}{RT^{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

Integrating Equation 20 and assuming ΔH^{o} constant, the following is derived:

$$\ln \alpha = - \frac{\Delta H^{o}}{RT} + C \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

in which

C = the integration constant

ΔH^{o} = the standard state enthalpy of reaction

R = the gas constant

T = the absolute temperature

That $C = \frac{\Delta S^{o}}{R}$ (Equation 21) can be shown as follows. The Gibb's free energy ΔF^{o} is defined as

$$\Delta F^{o} = \Delta H^{o} - T \Delta S^{o} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

or as

$$\Delta F^{o} = - RT \ln \alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Substituting $\Delta H^{o} - T \Delta S^{o}$ for ΔF^{o}, and rearranging, Equation 16 becomes

$$\ln \alpha = -\frac{\Delta H^{o}}{RT} + \frac{\Delta S^{o}}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

which is evidently more rational than Equation 21.

The equilibrium constant, α, is related to ΔH^{o} and ΔS^{o} according to Equation 23, and to ΔF^{o} according to Equation 16. The α is also related to the Langmuir adsorption equation through Equation 5 (non-competitive) and Equation 11 (competitive). Thus, if the α values are determined at selected experimental temperatures, thermodynamic variables, ΔH^{o}, ΔS^{o}, and ΔF^{o} can be calculated (Equations 23 and 16). The α values increase with increasing temperature in case of an endothermic reaction and decrease with increasing temperature in case of exothermic reaction (Figure 1). Theoretically α can be obtained from the intercept of linear plot of $C^{*}/\overline{X}^{*}$ vs. C^{*} (Figure 2). If the log α values thus obtained are plotted against the reciprocal of absolute temperature, the slope and the intercept of the resuling plot yields $-\Delta H^{o}/2.3R$ and $\Delta S^{o}/2.3R$ respectively (Figure 3). Thus from the equilibrium measurements of non-competitive (Equation 5) and competitive adsorption (Equation 11), the thermodynamic variables, ΔH^{o}, ΔS^{o}, and ΔF^{o}, can be calculated.

Interpretation of ΔH^{o}, ΔS^{o}, and ΔF^{o}

The enthalpy, ΔH^{o}, measures the bonding energy between the adsorbed bacteria and the soil particle at equilibrium. If ΔH^{o} is positive,

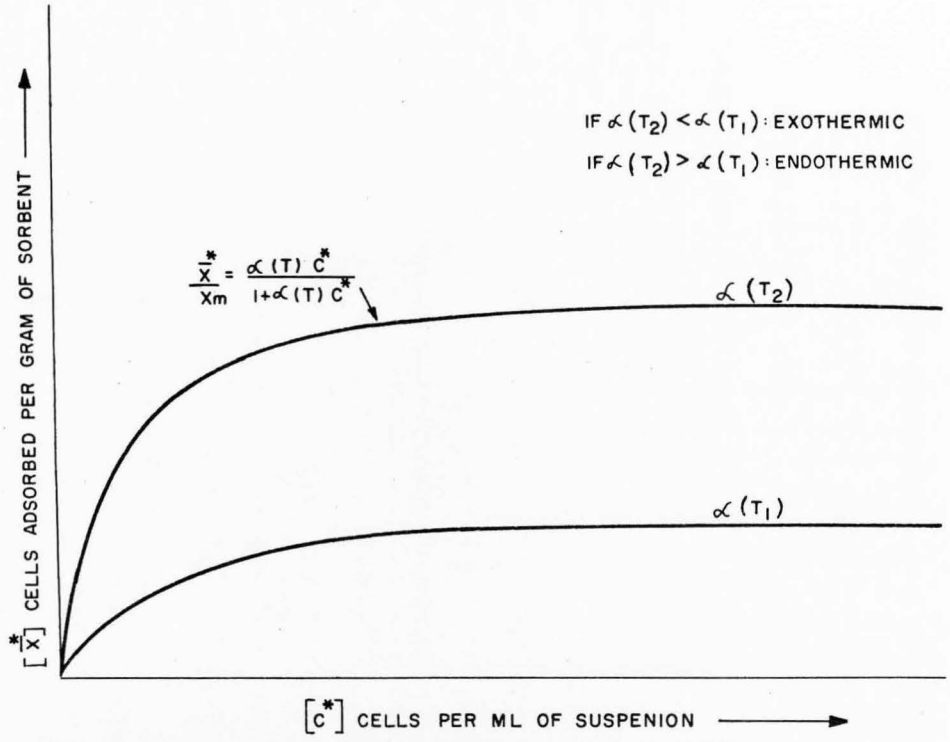

Figure 1. Theoretical Langmuir adsorption isotherms for bacteria on soil.

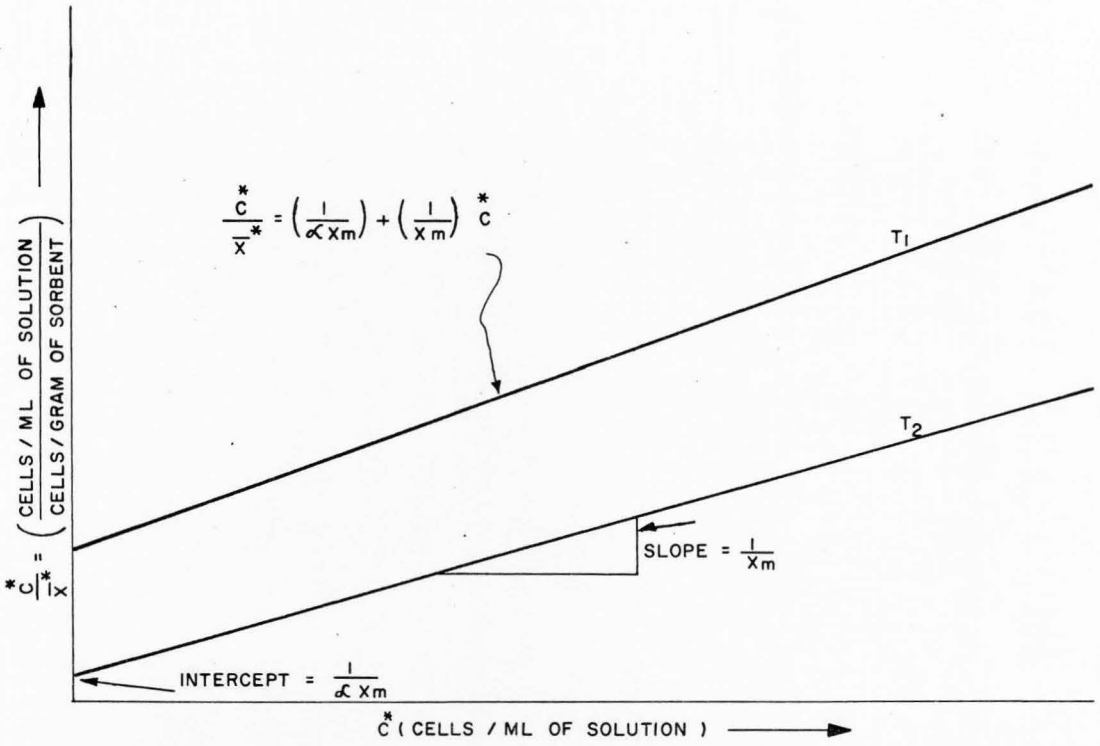

Figure 2. Theoretical linearized Langmuir isotherm plots.

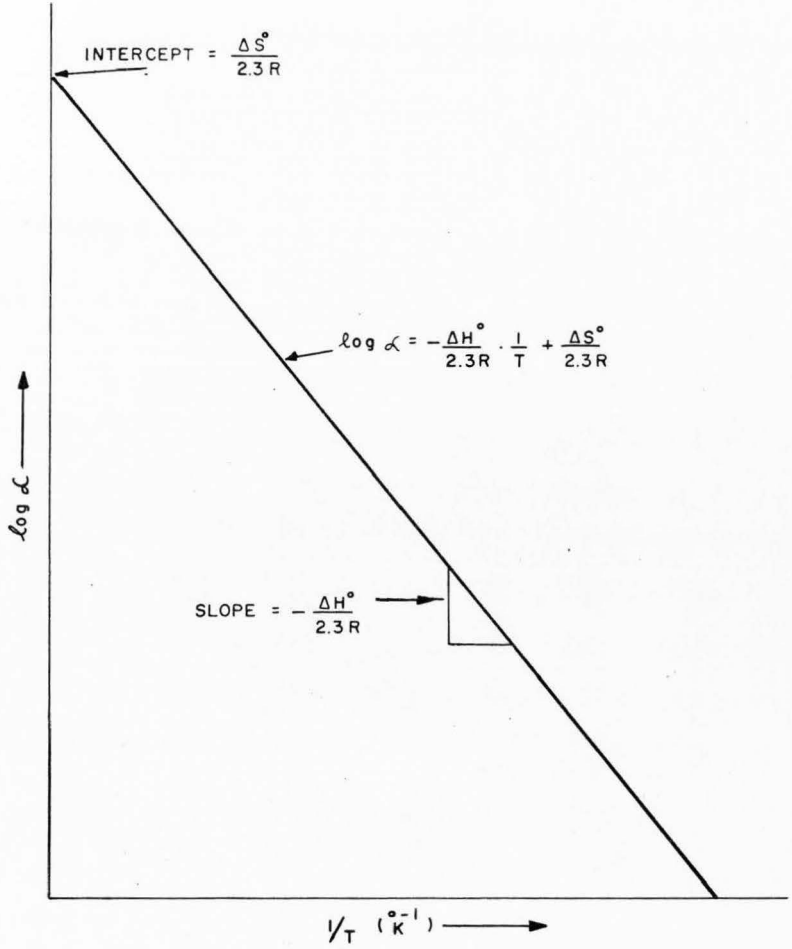

Figure 3. Theoretical determination of enthalpy and entropy of standard state from equilibrium data.

the adsorption is endothermic and bacteria are relatively weakly adsorbed on soil. On the other hand, if ΔH^{o} is negative, the adsorption is exothermic and the bacteria are relatively strongly adsorbed. The positive and negative ΔH^{o} values mean repulsion and attraction between sorbent and sorbate molecules respectively.

The entropy, ΔS^{o}, measures the difference in orderness or disorderness between the adsorbed bacteria and the bacteria in the solution. A positive entropy change due to the bacterial adsorption reaction means that the system is more disordered when the bacteria are in the adsorbed phase than they are in the solution phase. The reverse is true when the negative entropy change due to the bacterial adsorption reaction occurs.

The standard state free energy, ΔF^{o}, is a measure of the spontaneity of the reaction. The reaction is spontaneous if ΔF^{o} is negative and is non-spontaneous if ΔF^{o} is positive. Two terms, ΔH^{o} and $T\Delta S^{o}$ contribute to the value of ΔF^{o}. Thus either a positive value of ΔS^{o} or a negative value of ΔH^{o} can contribute to produce negative (spontaneous) value of ΔF^{o}. But, if the reaction is exothermic ($-\Delta H^{o}$) and ΔS^{o} is positive, both ΔH^{o} and $T\Delta S^{o}$ contribute to the spontaneity of reaction.

MATERIALS AND METHODS

The uptake of bacteria from the suspended phase to the adsorbed phase was determined by measuring the depletion of bacteria from the solution. This was done by providing opportunity for contact between the bacteria and soil particles through mixing. The bacterial concentrations were measured at selected time intervals until the uptake on soil was completed, which was assumed to be the equilibrium state. The number of bacteria depleted from suspension was assumed to be adsorbed by the soil sample; a control which contained bacteria in distilled water was used to verify this assumption. At equilibrium the designations $\overline{X}^*$ and C^* were used to indicate the concentration of bacteria on solid phase (number of bacteria per gram of soil) and in the suspension phase (number of bacteria per ml of suspension), respectively.

The values of $\overline{X}^*$ and C^* provided one point on the isotherm. Additional points at the same temperature described the complete adsorption isotherm. These points were obtained by varying the initial cell concentrations throughout the range of adsorption of interest. Isotherms at other temperatures were obtained by changing the temperature of the experimental system. Each isotherm provided the definition of the respective equilibrium constant as described earlier. Enthalpy ΔH^o, entropy ΔS^o, and free energy ΔF^o of

standard states were evaluated from equilibrium constants, also described previously.

Selection of Adsorbent

A homogeneous portion of Mendon silt loam, a soil from a nearby location, was used for all experimental work. The portion used was in the size less than 0.991 mm. The physical-chemical analysis of this homogeneous portion of that soil, hereafter referred to as simply Mendon silt loam, is given in Appendix M. Prior to experimental use, the soil samples were soaked in distilled water and auto-claved for 15 minutes at 121C. Mendon silt loam was chosen for the bacterial adsorption study since pilot experiments using this soil showed significant cell uptake.

Bacterium and Preparation

The bacterium chosen for this study was Staphylococcus aureus, FDA 209, a spherical coccus that readily breaks up into individual cells upon shaking. This organism was used in prior experiments involving other adsorbents as well as Mendon silt loam and did exhibit good adsorption.

To maintain this organism, primary stock cultures were transferred at monthly intervals on Nutrient Agar (Difco) slants, and, after sufficient growth, were stored at 5C. Stocks used were

made from the primary stocks as needed and transferred daily on Nutrient Agar slants. When an experiment was performed, the transfer for the next day's experiment was first made, then the slant (18 - 24 hours old) was used to prepare the suspension for the experiment. The slant was washed with 1 ml of sterile distilled water and the resulting suspension was then transferred drop by drop to a sterile screw cap test tube containing 10 ml of sterile distilled water, until the optical density at 525 mμ on a spectronic-20 calorimeter was 0.3. The tube was then shaken vigorously for 15 minutes to suspend the cells and break up the clumps. An optical density of 0.3 for the organism described here corresponds to approximately 3×10^8 cells per ml and served as a means of gross calibration for obtaining roughly the desired initial cell concentrations.

Selection of Competitive Sorbates

Sodium chloride (NaCl), sodium lauryl sulfate ($C_{11}H_{23}C(=O)-OSO_3Na$), and peptone were chosen to study their competitive effect on bacterial adsorption since they represent different categories of chemicals which may be found in contaminated waters which may flow underground and in other situation involving a bacteria-soil-organic matter--water contact opportunity. NaCl

represents the inorganic group of chemicals and is a major component of sewage. SLS represents the organic group of detergents and peptone represents the organic matter in a particular degraded protein. A definite chemical structure and the formula of peptone is not known. However, it is known that peptone is composed of short soluble peptide chains and amino acids.

Determination of Toxic Levels

Since the filter assay method counts only viable cells, the question arose whether the chemicals used as competitive sorbates might be toxic to S. aureus. In order to clarify this point, several toxicity experiments were conducted, using various concentrations of chemicals and bacterial cells. This was done by stirring bacteria-chemical suspensions in a suitable experimental flask, and taking samples at regular time intervals to measure the bacterial concentration in the presence of each of the chemicals. Soil was not added to any of these flasks during these experiments.

Determination of Threshold Competitive Levels

When two sorbates, say A and B, are competing for sorption sites, A may inhibit the adsorption of B. The threshold concentration level of A at which this occurs significantly, is called here for convenience in continued referrals, the "threshold competitive level" of A. To determine threshold competitive levels of NaCl, SLS and

and peptone, the concentrations of each given sorbate (alone) was increased in the presence of bacteria and soil to the point that measurable bacterial inhibition to adsorption was discerned. This was the point designated as the threshold competitive level. It was necessary that all these experiments were conducted below the threshold toxic levels of each of the chemical sorbates. The SLS concentration of .05 grams per liter was chosen to study its competitive effect on bacterial adsorption. This SLS concentration was below the threshold toxic level (Figure 8). Based on the results in Figure 14, a peptone concentration of 3.8 grams per liter was selected as a threshold competitive level. Even though NaCl did not show significant competition with bacteria for adsorption at 27C (Figure 16) 3 percent NaCl concentration was selected to determine the adsorption isotherms at 10C, 20C, 27C, and 37C. To assess threshold competitive levels, the initial cell concentration used was constant at 1×10^8 cells/ml throughout all experiments. This concentration range is in the flat portion of the bacterial adsorption isotherm as indicated in Figure 4.

Temperature control was accomplished by means of a large regrigerated-heated thermostatically controlled water bath. Temperature variation was less than $\pm$ 0.1C during the course of an experiment, at any of the temperatures used. Isotherms were determined at 10C, 20C, 27C, and 37C, respectively; the limits of viability of S. aureus controlled the working temperature range. Temperature

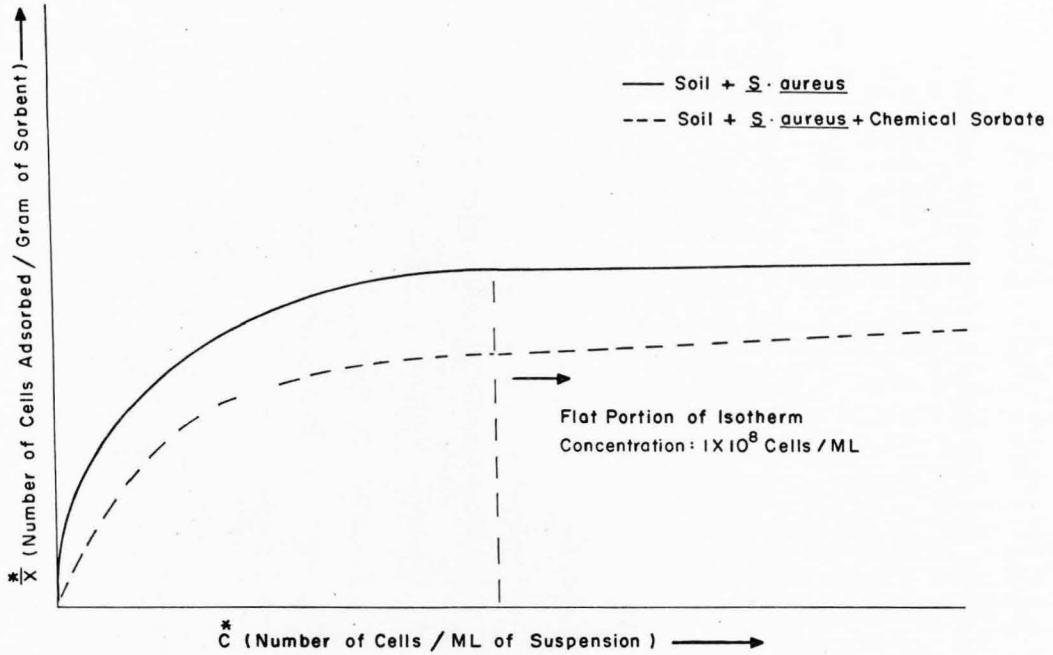

Figure 4. Theoretical bacterial adsorption isotherms with and without chemical competition.

equilibrium between the experimental flasks and constant temperature water bath was obtained in about three hours. Therefore, it was necessary to keep the experimental flasks in the constant temperature water bath at least three hours before performing the experiment.

Experimental Procedure

To prepare for adsorption experiments the following steps were followed.

1. All equipments and media were auto-claved at 121C for 15 minutes.

2. Experimental flasks containing the measured volume of sorbate solution (or distilled water depending on the type of run) of specified concentrations were prepared. Five flasks, as illustrated below, were done simultaneously:

Flask I: Distilled water + S. aureus (C_1)

Flask II: Distilled water + S. aureus (C_1) + soil (10 g)

Flask III: Competitive sorbate solution + S. aureus (C_1) + soil (10 g)

Flask IV: Competitive sorbate solution + S. aureus (C_2) + soil (10 g)

Flask V: Competitive sorbate solution + S. aureus (C_3) + soil (10 g)

The (C_1), (C_2), and (C_3) in the above experimental system indicate different initial bacterial concentrations.

Flask I was a "control," used to detect changes in bacterial population or clumping of cells, which may have occurred during the course of the experiment. Flask II was used to compare the bacterial adsorption magnitude with and without a competitive sorbate. The remaining three flasks (III, IV, and V) served to illustrate the effect of a given competitive sorbate on bacterial adsorption. Each flask contained a stir bar and was placed on an air-driven magnetic stirring mechanism in the thermostatically controlled water bath (± 0.1C), as indicated in Figure 5.

3. A bacterial suspension having a selected initial concentration was prepared using the spectronic-20 approximate method of adjustment. Stirring was initiated and the cells were then added to experimental flasks; stirring was of moderate intensity. Samples were taken from these flasks before the addition of soil, which served to give actual (approximate) initial cell concentrations in the respective flasks.

4. Ten grams of soil suspended in 100 ml of distilled water were added to each of the flasks (except Flask I). Stirring was halted at 5-, 15-, 30-, 45-, and 60-minute intervals, and the soil was allowed to settle down to the bottom of the flasks for three minutes; one ml samples from supernatants were then taken. Samples were diluted according to the dilution scheme shown in Figure 6.

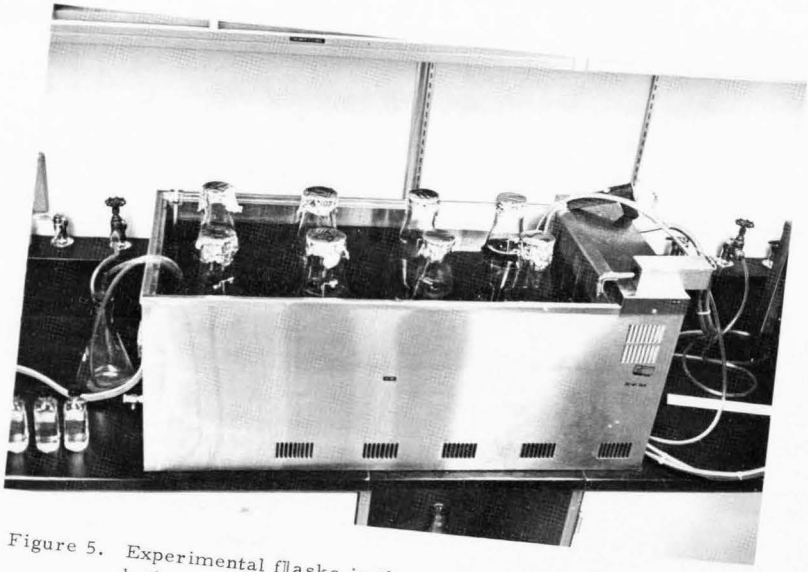

Figure 5. Experimental flasks in thermostatically controlled water bath.

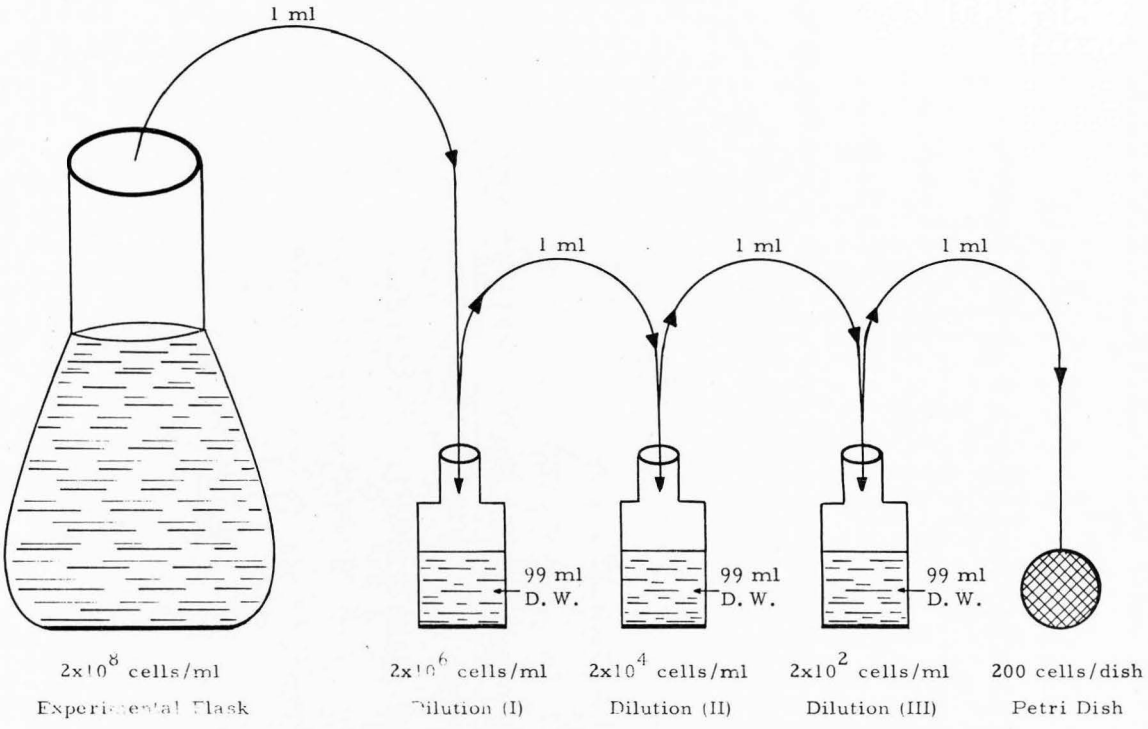

Figure 6. Diagramatic presentation of the dilution scheme.

5. After dilution, the samples were filtered through 0.45 μ membrane filters (Millipore Filter Corp.). The filters were then placed in petri dishes on pads containing 2.2 ml of double strength Brain Heart Infusion Broth (Difco). These samples were incubated at 37C for 18 - 24 hours. Bacterial colonies were then counted using stereomicroscope at 30x.

Evaluation of Bacterial Depletion and Uptake Curves

Bacterial colonies in the samples taken from the experimental flask at selected sampling intervals (at 0-, 5-, 15-, 30-, 45-, and 60-minute) were counted. The number of bacteria remaining in the soil-bacteria suspension was plotted against the sampling time, which resulted into a depletion curve (Figure 7A). The leveling point on this curve was taken as an equilibrium cell concentration in the solution phase, and was for convenience designated as C^* (cell/ml of solution). The number of cells depleted from soil-bacteria suspension was assumed to be adsorbed on soil. The number of bacteria adsorbed at selected sampling time was calculated using the following formula.

$$\overline{X} = \frac{(C_o - C) \text{ cells/ml} \cdot \text{volume-ml.}}{10 \text{ g soil}}$$

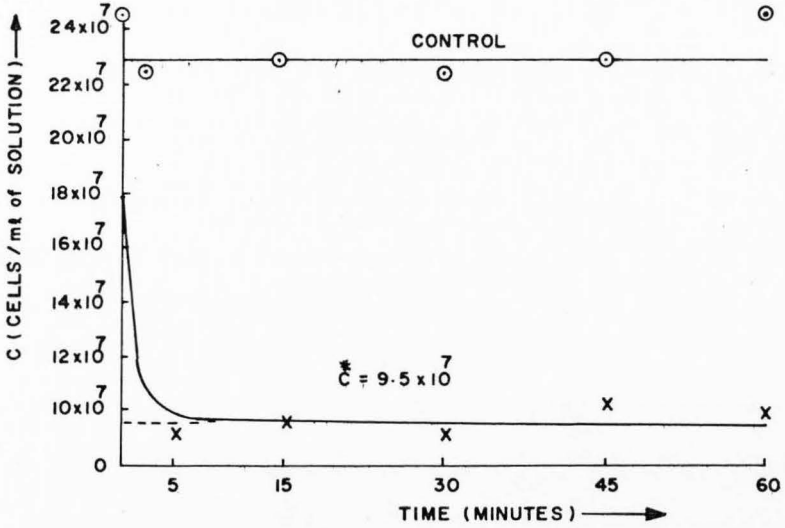

Figure 7A. Depletion of bacteria from solution-sample: 10 grams of Mendon silt loam soil.

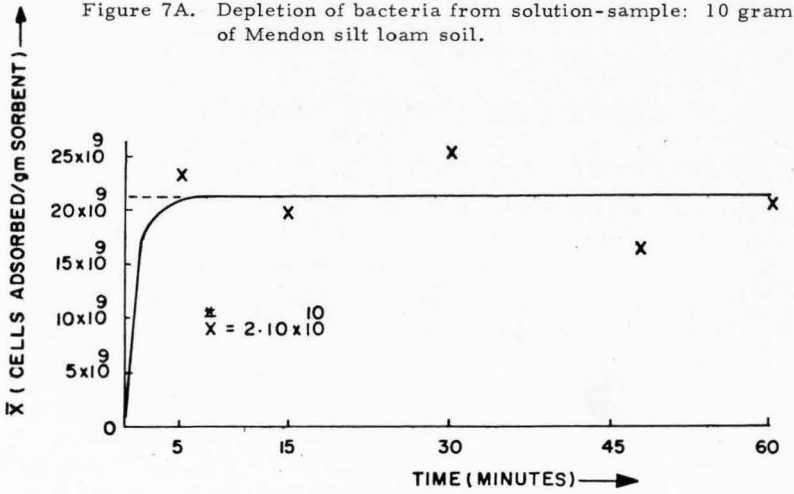

Figure 7B. Uptake of bacteria on solid phase.

where

$\overline{X}$ = the number of cells adsorbed/gram of soil at a selected sampling time

C_o = the initial cell concentration (cells/ml)

C = the cell concentration at a selected sampling time

The volume term refers to the total volume of the bacteria-soil-water suspension in the experimental flask. A plot of $\overline{X}$ vs. the sampling time was made which yielded a bacterial uptake curve (Figure 7B). The leveling point on this curve, was taken as a equilibrium cell concentration on solid phase, which for convenience was designated as $\overline{X}^*$ (cells/gram of soil).

Determination of Adsorption Isotherms

An adsorption isotherm is, in graphical form, a plot of equilibrium concentrations in solid and liquid phases, $\overline{X}^*$ and C^*, respectively. Each bacterial adsorption experiment provided a single point for defining an experimental isotherm. The locus of best fit for a number of such points obtained at a given temperature defines completely such an experimental isotherm. Such isotherms were obtained for temperatures of 10C, 20C, 27C, and 37C, for all sorbate-sorbent systems studied.

The best fit locus of points was obtained by regression analysis of the Langmuir isotherm in linearized form:

$$\frac{C^*}{X^*} = \frac{1}{\alpha X_m} + \frac{1}{X_m} \cdot C^* \quad \ldots\ldots\ldots \quad (24)$$

The regression analysis of the set of experimental points is done by the computer program listed in Appendix B. Appendix B also illustrates the numerical and graphical output from this program. The output from this computerized analysis of experimental points yields the Langmuir constants α and X_m. Figure 28B shows a sample of a best fit linearized Langmuir isotherm, (Equation 24). Figure 28C shows the same experimental points plotted in the conventional form of the Langmuir isotherm, (Equation 5). The curves drawn in Figures 28B and 28C were based upon the values of α and X_m shown in the printout, Figure 28A.

Evaluation of Enthalpy (ΔH^o), Entropy (ΔS^o) and Free Energy (ΔF^o) of Standard State

In order to evaluate the standard state enthalpy, ΔH^o, a plot of log α versus reciprocal of absolute temperature was made in accordance with Equation 21. As indicated in Equation 21, the slope of such a plot is $-\Delta H^o/2.3R$, which will then yield enthalpy of standard state, ΔH^o. After determining ΔH^o, the standard state entropy (ΔS^o) and standard state free energy (ΔF^o) were calculated using Equations 23 and 22, respectively.

Data Processing

All experimental data were recorded on IBM coding sheets, punched on cards, and processed by commensurate computer programs. This was done for two reasons. First such processing facilitated retrieval and analysis of large quantities of data at any stage of processing whether as initial raw data or in processed form. The manner of cataloging data and results and the formats for display of each, in printed and graphical form, insured this. Second such processing eliminated large quantities of manual calculation, which released labor for other tasks and minimized chances for mistakes in data processing.

The complete data processing consisted of two phases described as follows.

A. Processing of bacterial depletion data.

1. Bacterial depletion data were recorded on IBM coding sheets as indicated in Figures 21A and 21B.
2. These data were punched on IBM cards.
3. The data cards were put together along with the BACIXT program (Figure 23) as shown in Figure 22 and were processed on Univac 1108.
4. The output of the above processing consisted of:

a. Tabular output consisting of bacterial concentration observed at selected sampling intervals in both solution and adsorbed phases (Figure 24A).

b. A curve showing the bacterial uptake with time (Figure 24B). The leveling point of this curve yielded a value of equilibrium cell concentration in solid phase, $\overline{X}^*$.

c. A curve showing the bacterial depletion with time (Figure 24C). The leveling point of this curve resulted in a value for equilibrium cell concentration in solution phase, C^*.

B. Processing of equilibrium data.

1. The equilibrium data obtained from 4b and 4c were recorded on another IBM coding sheet as indicated in Figure 25.

2. These data were punched on IBM cards.

3. The data cards were arranged with the ALPHAB program (Figure 27) as shown in Figure 26 and processed on Univac 1108.

4. The output of above processing consisted of:

a. Table showing the numerical values of α, X_{max}, R, and R^2 values (Figure 28A).

b. Langmuir (Figure 28C) and linear Langmuir (Figure 28B) isotherms.

RESULTS--THRESHOLD TOXIC AND COMPETITIVE LEVELS

Toxicity of Chemical Sorbates to S. aureus

The results of tests to determine threshold toxicity concentrations of SLS, peptone, and sodium chloride to S. aureus are outlined below. For each test a control containing only distilled water and S. aureus was used. Appendices C, D, and E show partial results of the toxicity tests for each of these chemicals. Each assay was done at the end of one hour contact time.

Sodium lauryl sulfate

Figure 8 summarizes the results of tests for determining the toxic effect of SLS on S. aureus. Figure 8 shows a marked effect on cell viability is caused by increasing SLS concentration; the threshold point of significant toxic effect appears to be .05 gram per liter. It should be noted that 0.5 gram per liter SLS caused 100 percent depletion of bacteria from solution (Figure 8).

Peptone

Figure 9 shows the results of toxicity testing between S. aureus and peptone at concentrations of 1.0, 10.0, and 30.0 grams per liter. Even at the highest peptone concentration of 30 grams per liter, Figure 9 shows no indication of toxicity. This

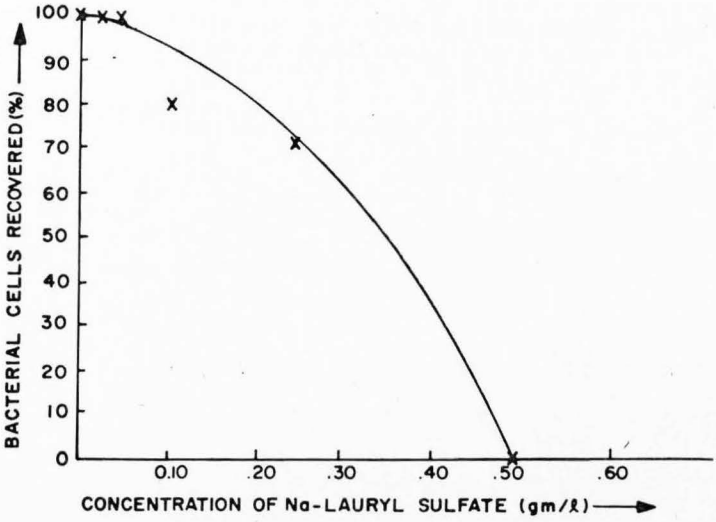

Figure 8. Toxic effect of Na-lauryl sulfate to Staphylococcus aureus at 27C.

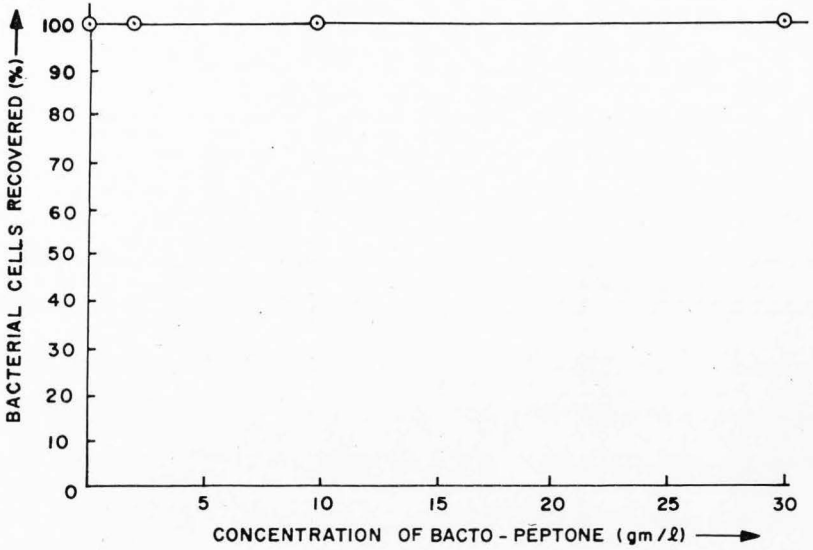

Figure 9. Toxic effect of peptone to Staphylococcus aureus at 27C.

concentration level is substantially higher than any levels which could be encountered under even the most adverse conditions. Therefore, peptone toxicity is not a problem for these tests.

Sodium chloride

Results in Figure 10 indicate that no depletion in bacterial population occurred until NaCl concentration was increased beyond 100 grams per liter. Since this concentration value is also beyond practical experimental limits, sodium chloride toxicity was not a problem for these tests.

Threshold Competitive Levels of Chemical Adsorbates

The results of tests to determine the competitive effect of SLS, peptone, and NaCl on bacterial adsorption are discussed below. These tests were conducted to determine the concentration levels of each of these chemicals at which substantial impairment of bacterial adsorption occurs; this level is designated "threshold competitive level." Appendices F, G, and H show the results of selected runs involving bacterial competition with each of these chemicals.

Sodium lauryl sulfate

Even though .05 gram per liter of SLS showed no competition with bacteria for adsorption at 27C (Appendix F), this concentration was selected to determine the adsorption isotherms at 10C, 20C, and

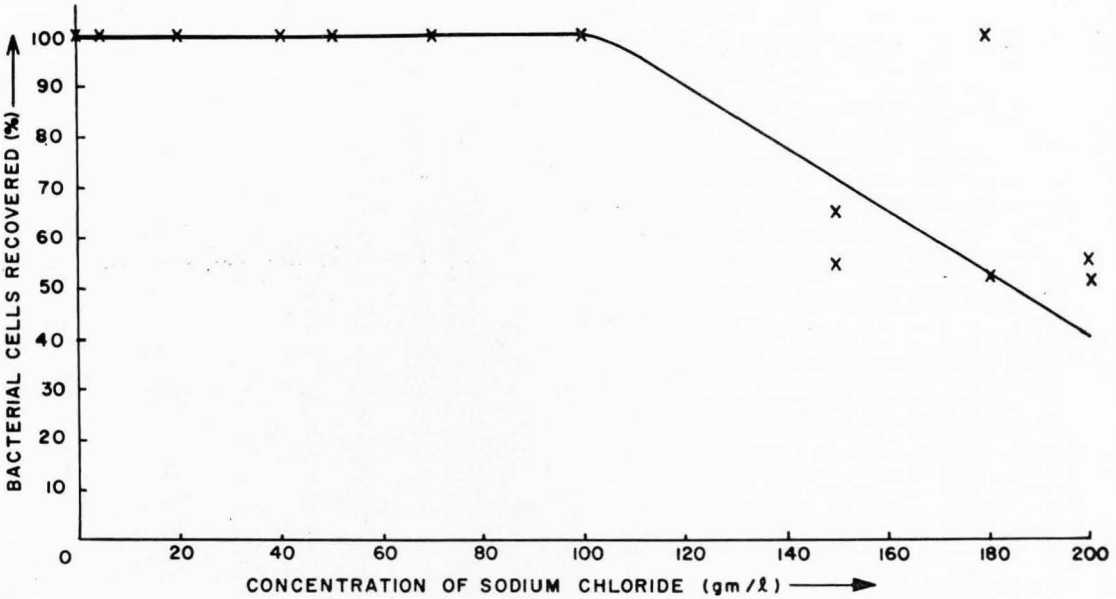

Figure 10. Toxic effect of sodium chloride on Staphylococcus aureus at 27C.

37C, since higher SLS concentrations proved to be toxic to S. aureus (Figure 8). Using this SLS concentration (.05 gram per liter), a noticeable cell uptake occurred at 27C (Figure 11) but when temperature was lowered to 10C, no bacterial adsorption was observed (Figure 12). This suggests that .05 gram per liter of SLS inhibits the bacterial adsorption at 10C but not at 27C.

Though no bacterial uptake occurred at 10C in .05 gram per liter of SLS solution, significant adsorption did occur (Figure 13) at this temperature when the initial cell concentration was decreased by tenfold (1×10^7 cells/ml) and that of SLS was cut down by one-fifth (.01 gram per liter).

Peptone

Figure 14 shows the effect of peptone competition with S. aureus for adsorption. These results were obtained using identical conditions in each test except for the peptone concentration. Figure 14 shows zero uptake of cells at peptone concentrations greater than 6 grams per liter. As can be seen from Figure 14, bacterial uptake was decreased linearly with increasing concentrations of peptone. A peptone level of 3.8 grams per liter, based on the results in Figure 14, was chosen to study peptone's competitive effect on bacterial adsorption. However, no cell uptake was observed at 10C in the presence of peptone (3.8 grams per liter) as indicated in Figure 15.

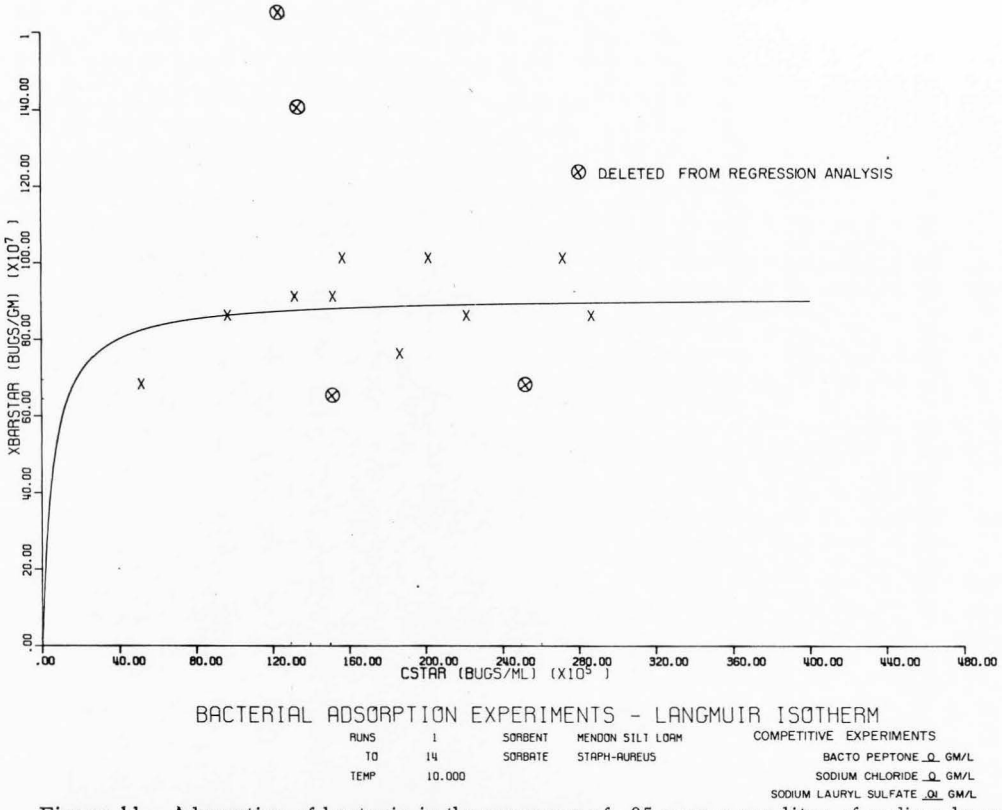

Figure 11. Adsorption of bacteria in the presence of .05 grams per liter of sodium lauryl sulfate at 27C.

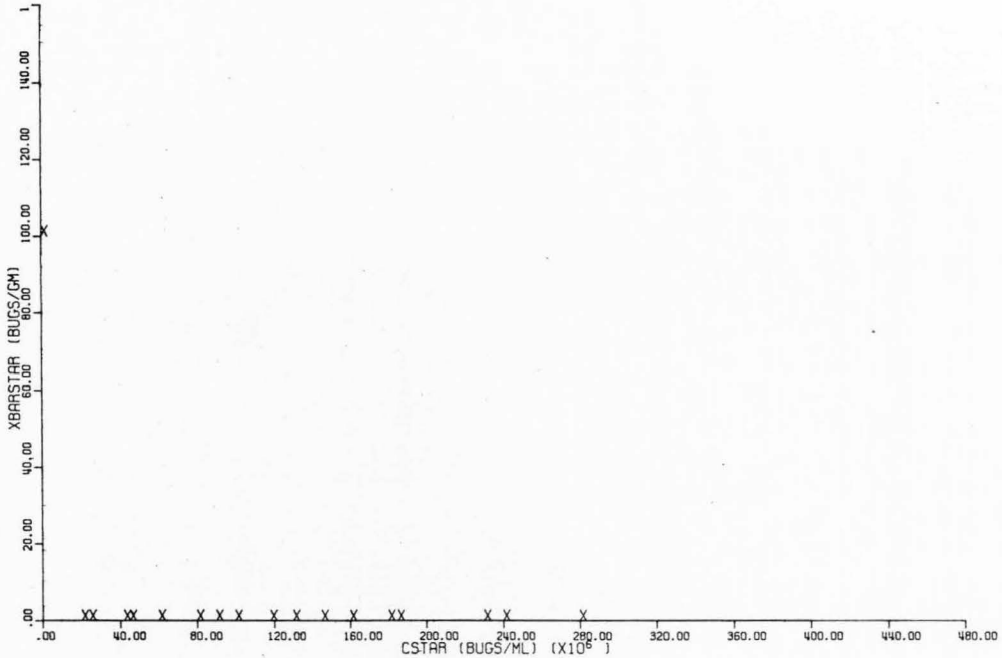

Figure 12. Adsorption of bacteria in the presence of .05 gram per liter of sodium lauryl sulfate at 10C.

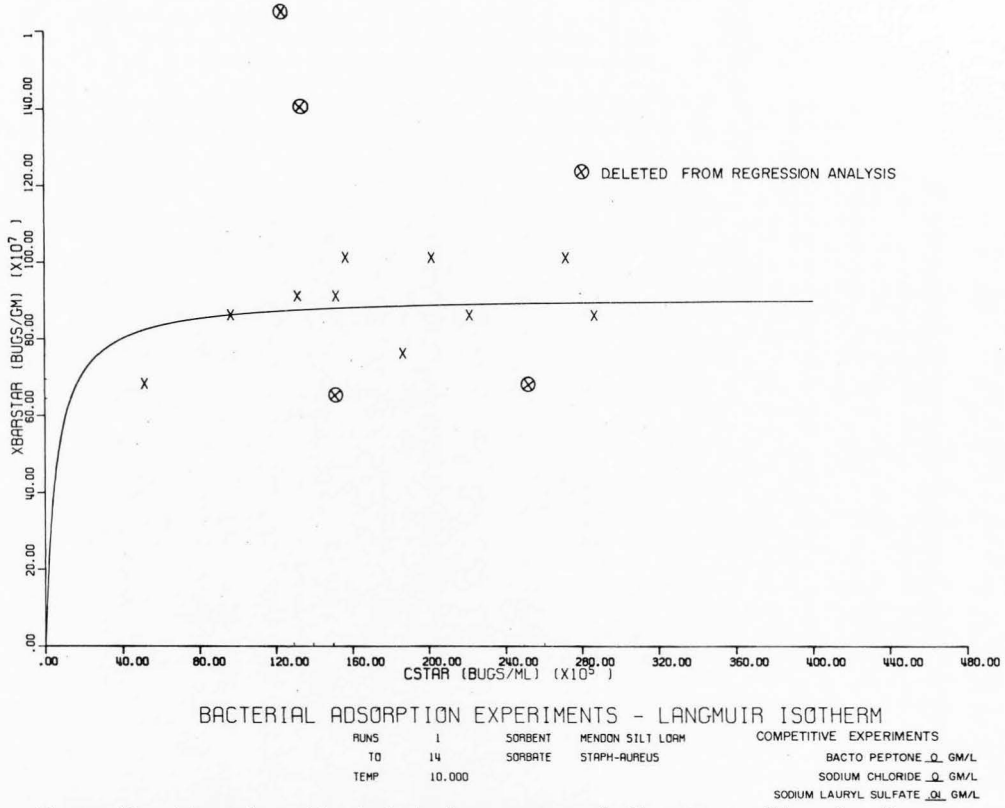

Figure 13. Adsorption of bacteria in the presence of .01 gram per liter of sodium lauryl sulfate at 10C.

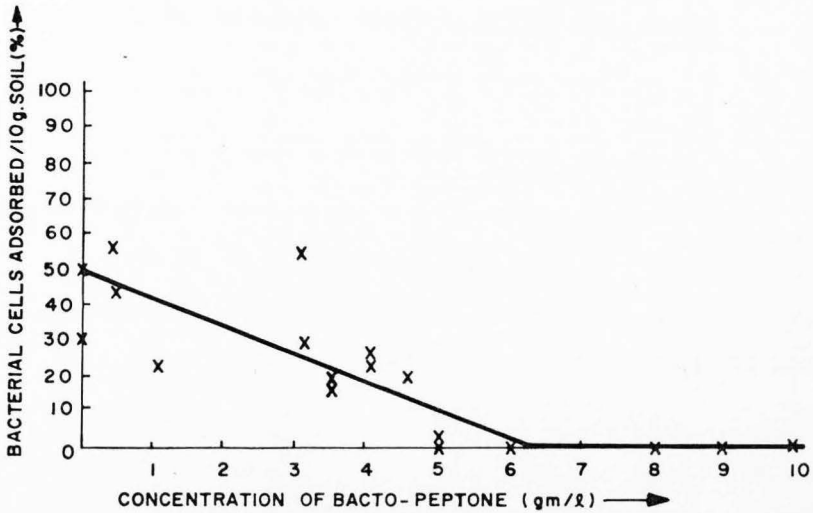

Figure 14. Effect of various concentrations of peptone on bacterial adsorption at 27C.

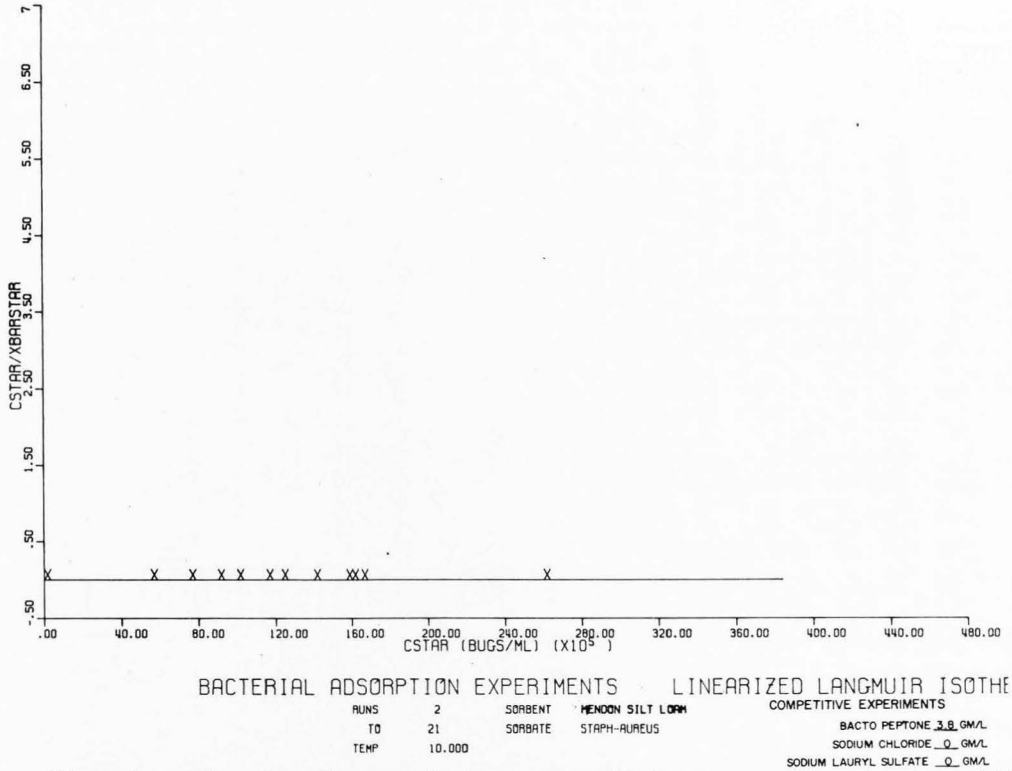

Figure 15. Adsorption of bacteria in the presence of 3.8 grams per liter of peptone at 10C.

Sodium chloride

A wide NaCl concentration range (.06 gram to 200 grams per liter) was tested to determine its ability to compete with bacteria for sorption sites. Results of these experiments are shown in Figure 16, which indicate no competition of NaCl with bacteria for sorption. NaCl is a strong electrolyte and tends to remain in solution rather than go towards the interface. Bacterial cells are proteins which have hydrophilic as well as hydrophobic groups. The hydrophobic group might influence bacteria to tend towards the soil-solution interface, possibly resulting in their adsorption on soil particles. Even if Na^+ is adsorbed, which is quite likely, its hydrated radius ($0.98A^o$) is comparatively smaller than that of bacteria ($100A^o$), suggesting that Na^+ may not be occupying all the space provided by adsorption sites but could leave enough room for bacterial cells to adsorb. Thus NaCl could be acting noncompetitive to bacteria. Bacterial cells are amphoteric in nature, i.e., individual cells have both positive as well as negative charges. If it is assumed that bacteria are preferably adsorbed by soil particles, they might have formed a coating around the soil particles, which left positive ends outside, that could possibly have caused Na^+ to repel from sorption sites. This, again, explains the noncompetitive behavior of Na^+. Though no competitive level of NaCl was observed experimentally, 30 grams per liter of NaCl concentration was selected for investigating adsorption isotherms at different temperatures.

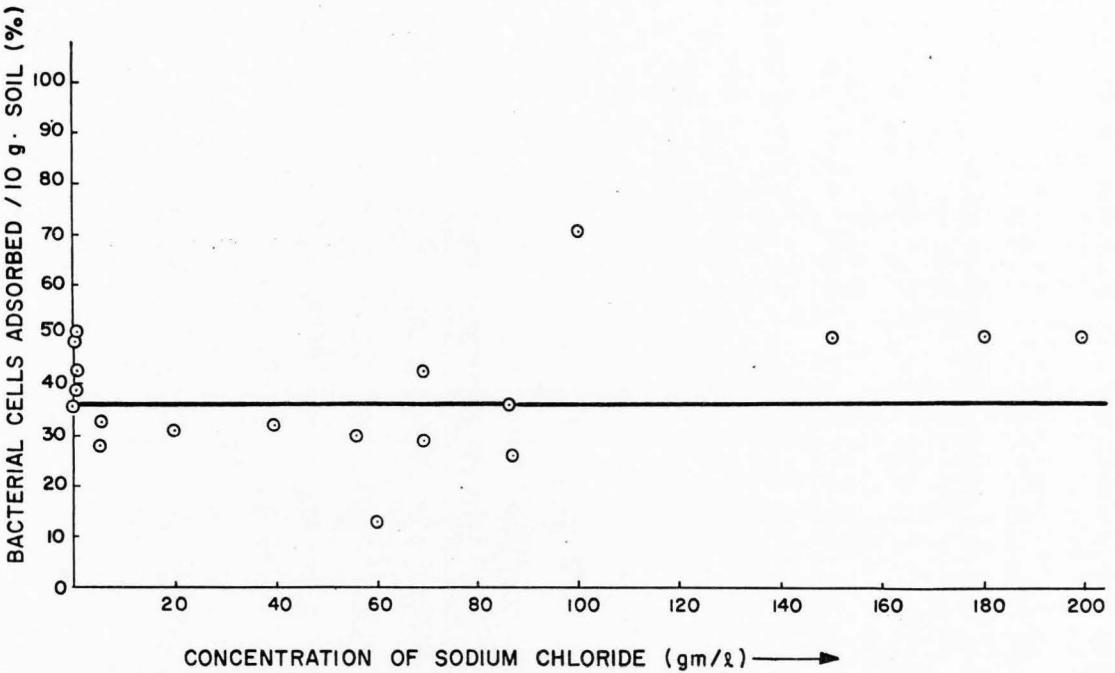

Figure 16. Effect of various concentrations of sodium chloride on bacterial adsorption at 27C.

RESULTS--EQUILIBRIUM ISOTHERMS AND THERMODYNAMIC ANALYSIS

To study the competitive effect of chemical sorbates (SLS, peptone, and NaCl) on the bacterial adsorption the following sorbent-sorbate systems were used.

1. Mendon silt loam + S. aureus
2. Mendon silt loam + S. aureus + Na-lauryl sulfate
3. Mendon silt loam + S. aureus + peptone
4. Mendon silt loam + S. aureus + NaCl

Among the above listed systems, the first one served as non-competitive and the remaining three acted as competitive. Bacterial adsorption isotherm results (α, X_{max}, and R^2) and their interpretation in terms of thermodynamics (ΔH^o, ΔS^o, and ΔF^o) for each of the above mentioned systems are discussed below.

Mendon Silt Loam + S. Aureus

Isotherms

The complete set of bacterial adsorption isotherms for Mendon silt loam - S. aureus system, at 10C, 20C, 27C, and 37C, is presented in Appendix I, in both conventional Langmuir and linear Langmuir forms. The complete computer analysis for each isotherm precedes the graphical figures. Results of the computer analysis giving α,

X_{max} and R^2 for this system are summarized in Table 1, along with the results from all other systems tested. The regression coefficient values, R^2, were .001, .961, .587, and .992 for 10C, 20C, 27C, and 37C respectively. The lower R^2 value observed at 10C could be attributed to the deviation of some equilibrium data points from the best fit line, computed by least square regression analysis using linear transformation of Langmuir isotherm (Equation 24). The data in Table 1 show an increase in X_{max} values with increasing temperature, from 10C to 37C. This indicates that the capacity of Mendon silt loam to adsorb bacteria increases with increasing temperature.

Thermodynamic analysis

The results given in Table 1 for α are plotted against $1/T(^{o}k^{-1})$ in accordance with Equation 23, in Figure 17. It is clear that the bacterial reaction in the absence of chemical sorbate is endothermic as α increases significantly with increasing temperature in accordance with an endothermic reaction (refer to section, Thermodynamics of Adsorption, p. 24). The measurement of the slope and the intercept in the Figure 17 curve yields a value for ΔH^{o} of + 8.500 kcal·mole^{-1} and ΔS^{o} of + 92.0 e.u. The ΔF^{o} values, calculated using Equation 16, ranged from -17.50 to -19.50 kcal·mole^{-1} for the non-competitive system (Table 1).

For all the sorbent-sorbate systems listed earlier, it was assumed that the enthalpy change, ΔH^{o}, due to the bacterial

Table 1. Results of adsorption isotherms for indicated sorbent-sorbate systems.

Sorbent	Sorbate(s)	R	R^2	T(°C)	$\frac{1}{T}X10^{-3}(^oK^{-1})$	X^a_{max}	α^a	$\Delta H^{o\,b}$ (k cal-mole^{-1})	$\Delta S^{o\,c}$ (e. u.)	$\Delta F^{o\,d}$ (k cal-mole^{-1})
Mendon silt loam	S. aureus	0.035	0.001	10	3.55	$0.110X10^{11}$	$3.10X10^{13}$		92.0	-17.50
		0.980	0.961	20	3.41	$0.149X10^{11}$	$5.10X10^{13}$		92.0	-18.50
		0.766	0.587	27	3.33	$0.200X10^{11}$	$8.00X10^{13}$	8.500	92.0	-19.10
		0.996	0.992	37	3.24	$0.280X10^{11}$	$10.00X10^{13}$		92.0	-19.90
Mendon silt loam	S. aureus	0.00	0.00	10	3.55	0.00	No adsorption		--	--
	+	0.950	0.903	20	3.41	$0.105X10^{11}$	$2.13X10^{14}$	3.720	79.0	-19.28
	Na-lauryl sulfate	0.829	0.687	27	3.33	$0.916X10^{10}$	$2.44X10^{14}$		79.0	-20.08
		0.945	0.892	37	3.24	$0.154X10^{11}$	$2.74X10^{14}$		79.0	-20.78
		0.00	0.00	10	3.55	0.00	No adsorption		--	--
		0.986	0.972	20	3.41	$0.110X10^{10}$	$1.48X10^{14}$		147.0	-18.50
Mendon silt loam	S. aureus	0.879	0.772	27	3.33	$0.204X10^{10}$	$0.715X10^{14}$	24.00	144.0	-19.50
	+	0.993	0.985	37	3.24	$0.131X10^{10}$	$4.60X10^{14}$		145.0	-21.00
	Peptone									
		0.737	0.543	10	3.55	$0.238X10^{11}$	$3.12X10^{12}$		138.0	-16.00
Mendon silt loam	S. aureus	0.982	0.983	20	3.41	$0.909X10^{10}$	$5.45X10^{13}$	23.00	141.0	-18.40
	+	0.818	0.669	27	3.33	$0.738X10^{11}$	$2.25X10^{13}$		138.0	-18.50
	NaCl	0.979	0.959	37	3.24	$0.942X10^{10}$	$4.75X10^{13}$		138.0	-19.80

[a] Calculated by regression analysis using the linear transformation of Langmuir isotherm: $\left(\frac{C^*}{\overline{X}^*} = \frac{1}{\alpha X_m} + \frac{1}{X_m} \cdot C^*\right)$.

[b] Evaluated by measurement of slope of the experimental plot for: $\log \alpha = -\frac{\Delta H^o}{2.3\,R} \cdot \frac{1}{T} + \frac{\Delta S^o}{2.3\,R}$.

[c] Obtained from intercept of experimental plot for equation: $\log \alpha = -\frac{\Delta H^o}{2.3\,R} \cdot \frac{1}{T} + \frac{\Delta S^o}{2.3\,R}$.

[d] Calculated using equation, $\Delta F^o = -RT \ln \alpha$.

Table 1A. Thermodynamic functions of upper and lower envelope boundaries of van't Hoff's plots [1/]

	Best estimate fit [2/]			Lower bound, a			Upper bound, b		
	ΔH^o	ΔS^o	ΔF^o 37^oC	ΔH^o	ΔS^o	ΔF^o 37^oC	ΔH^o	ΔS^o	ΔF^o 37^oC
Mendon silt loam	8.50	92	-19.	same			same		
Mendon silt loam + Na-lauryl sulfate	3.72	79	-19.	same			same		
Mendon silt loam + peptone	24.0	145	-20.	12.8	107	-19.2	35.6	190	-18.4
Mendon silt loam + NaCl	23.0	138	-19.	19.1	125	-18.4	41.5	150	- 3.5

[1/] Figures 17-20 respectively.

[2/] Table 1.

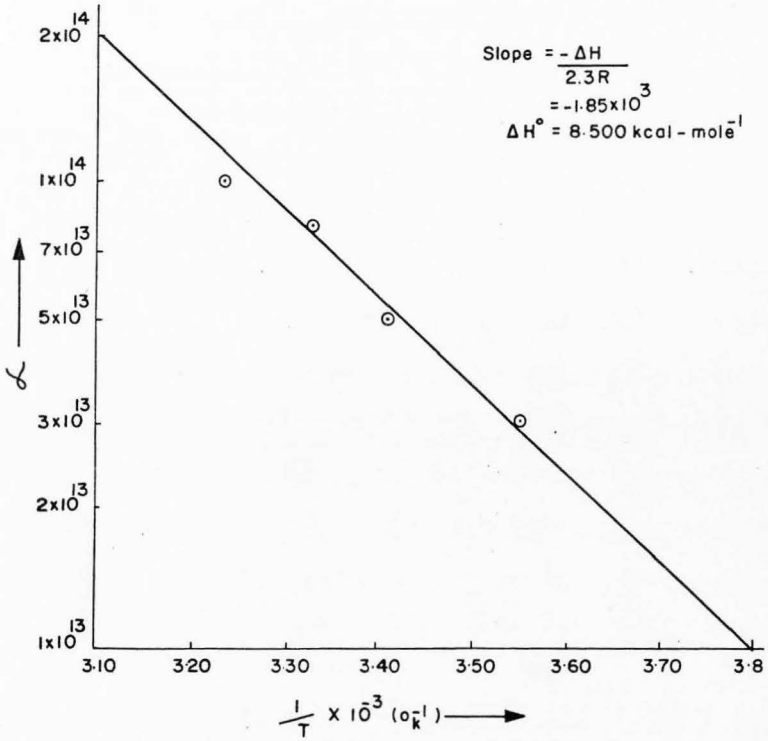

Figure 17. Evaluation of standard state enthalpy, ΔH^{o}, for Mendon silt loam-S. aureus adsorption system, using van't Hoff's equation.

adsorption reaction remains constant over the selected range of temperature (10C to 37C). A positive sign on ΔH^{o} indicates that the bacterial adsorption on soil is endothermic. This also suggests that the bacteria are relatively weakly adsorbed on soil particles. Both soil particles (Lyon, Buckman, and Brady, 1952, p. 93) and bacteria (Lamanna and Mallette,1965, p. 275) have a net negative charge. A positive ΔH^{o} (+8.50 kcal·mole^{-1}) value could be attributed to the repulsive reaction between the bacteria and soil particles during the process of bacterial adsorption.

A positive ΔS^{o} value (+ 92.0 e.u.) observed for this system suggests that the system has more freedom when the bacteria are in the adsorbed phase. That the increase in entropy due to solvation is greater than the decrease in entropy due to adsorption could have resulted into a net positive entropy change for this system.

It can be seen from Equation 22 that the two contributions, ΔH^{o} and $T\Delta S^{o}$, are involved in the value of ΔF^{o}. For endothermic reaction ($+\Delta H^{o}$) $T\Delta S^{o}$ is the factor that forces ΔF^{o} to be negative. This seems to be the case in the bacterial adsorption reaction, since positive ΔH^{o} values (Table 1) indicate the endothermic nature of the reaction. As the absolute temperature increases, the influence of entropy on the value of ΔF^{o} also increases (Equation 22).

The negative ΔF^{o} values (-17.50 kcal·mole^{-1} to -19.50 kcal·mole^{-1}) observed for this sorbent-sorbate system indicate that the bacterial adsorption in the absence of chemical sorbate is spontaneous for the bacterial concentrations used.

Mendon Silt Loam + S. aureus + Sodium Lauryl Sulfate

Isotherms

Appendix J shows the complete set of adsorption isotherms, for Mendon silt loam - S. aureus - SLS system. This includes graphical figures of both Langmuir and linear Langmuir isotherms along with the tabular output consisting of α, X_{max}, and R^2 values for respective isotherms, obtained at 10C, 20C, 27C, and 37C. As was observed in the non-competitive system, X_{max} values increased with increasing temperature for this system. However, these X_{max} values were lower (except at 27C) than those observed for non-competitive systems (Table 1), indicating the inhibition of bacterial adsorption in the presence of SLS. The R^2 values were 0.0, .903, .687, and .892 for 10C, 20C, 27C, and 37C, respectively (Table 1). Since there was no bacterial adsorption at 10C in the presence of SLS, R^2 value at this temperature turned out to be zero.

Thermodynamic analysis

The observed α values (Table 1) for this adsorption system are plotted against 1/T in accordance with Equation 23, in Figure 18.

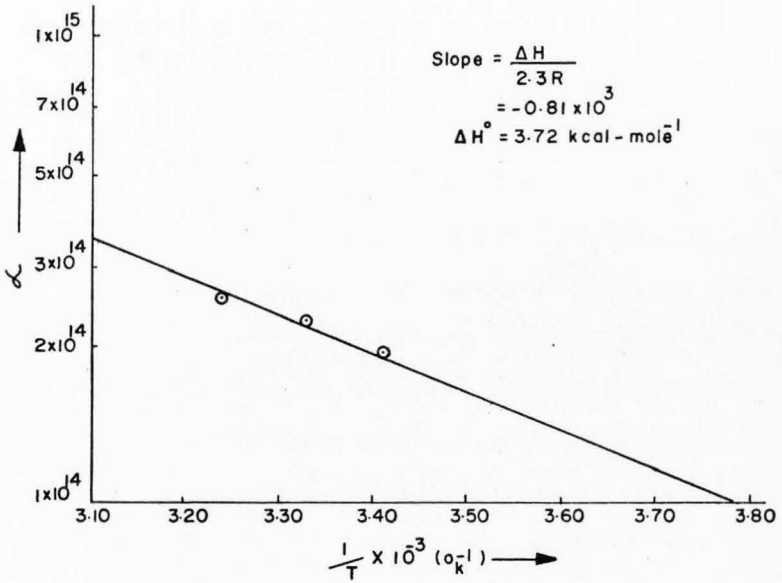

Figure 18. Evaluation of standard state enthalpy, ΔH^{o}, for Mendon Silt loam-*S. aureus*-Na-lauryl sulfate adsorption system, using van't Hoff's equation.

The measurement of slope and intercept in Figure 18 curve yields a ΔH^{o} value of + 3.720 kcal·mole^{-1} and a ΔS^{o} value of + 79.0 e.u. respectively. The ΔF^{o} values calculated using Equation 16 ranged from - 19.28 to - 20.78 kcal·mole^{-1}.

The ΔH^{o} value (+ 8.500 kcal·mole^{-1}) for the non-competitive system indicates that the bacterial adsorption in the presence of SLS is relatively less endothermic. The lower ΔH^{o} (+ 3.720 kcal·mole^{-1}) observed for this sorbent-sorbate system could be attributed to relatively less repulsion between bacteria and soil particles in the presence of SLS, during the process of adsorption. The ΔS^{o} value (+ 79.0 e.u.) for this system was also lower than that observed in the non-competitive system (+ 92.0 e.u.). The comparison of these two ΔS^{o} values indicate that there is slightly more restriction on adsorbed bacteria in the presence of SLS than they have in the absence of SLS. Since observed ΔH^{o} for this adsorption system is still positive (+ 3.720 kcal·mole^{-1}), the $T\Delta S^{o}$ term is a major contributor to the negative values of ΔF^{o} (Equation 22). The observed ΔF^{o} values (- 19.28 to - 20.18) suggest that the bacterial adsorption is spontaneous even in the presence of SLS.

Mendon Silt Loam + S. aureus + Peptone

Isotherms

A summary of isotherm results (i.e. α, X_{max}, and R^2) for

this sorbent-sorbate system is presented in Table 1, also. The complete computer analysis of isotherms, and their conventional and linear graphical presentations, obtained at 10C, 20C, 27C, and 37C are shown in Appendix K. The regression coefficients were .972, .772, and .985 for 20C, 27C, and 37C, respectively (Table 1). The R^2 value was zero (Table 1) at 10C because no bacterial adsorption occurred at this temperature, for this system. The data in Table 1 show that X_{max} values observed for this system were lower than those noticed in non-competitive systems, indicating the competition of peptone with S. aureus for adsorption.

Thermodynamic analysis

The equilibrium constant, α, values observed for this system are shown in Table 1. These α values are plotted against 1/T in Figure 19. The measurement of slope of Figure 19 curve yields a ΔH^o value of + 24.0 kcal·mole^{-1}. The observed ΔF^o values were all negative and ranged from - 18.50 to - 21.00 kcal·mole^{-1}.

The highest ΔH^o (+ 24.0 kcal·mole^{-1}) observed for this sorbent-sorbate system indicates that the bacterial adsorption is relatively much more endothermic in the presence of peptone. Peptone closely resembles tryptone; tryptone has been found to desorb virus particles from carbon (Cookson and North, 1967). This

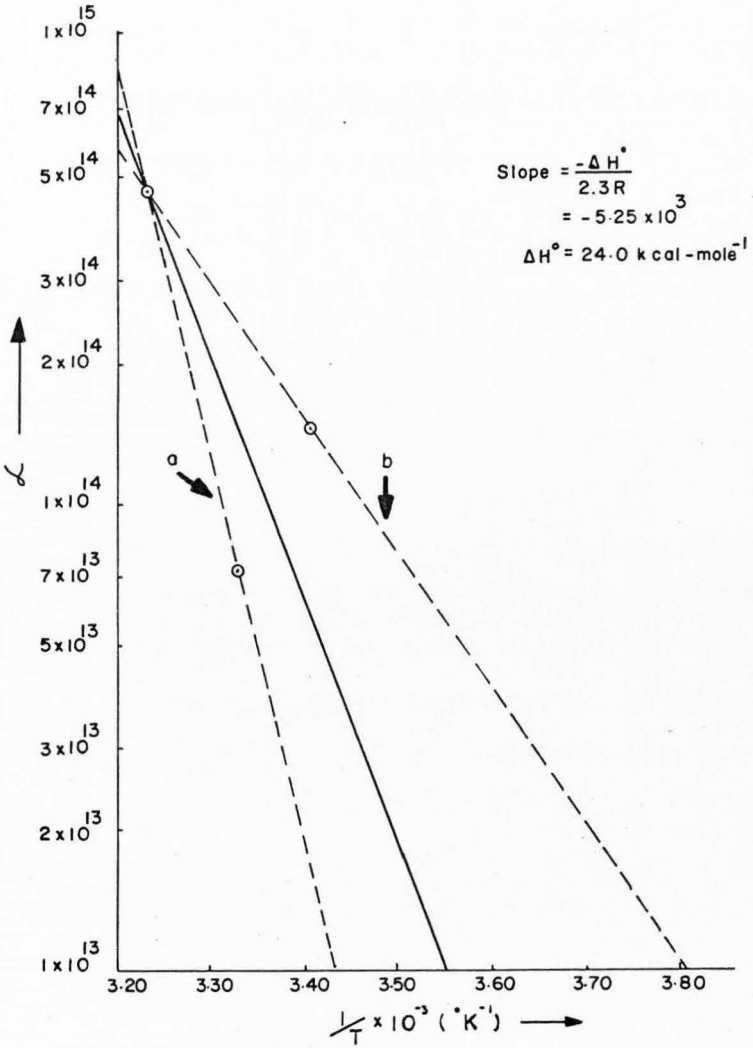

Figure 19. Evaluation of standard state enthalpy, ΔH^{o}, for Mendon silt loam-S. aureus-peptone adsorption system, using van't Hoff's equation.

suggests that peptone could possibly desorb bacteria from soil. To overcome the desorbing action of peptone, some additional amount of energy might be required which might have yielded a relatively high ΔH^{o} (24.0 kcal·mole^{-1}) for this adsorption system. Results in Table 1 show that ΔS^{o} values (+ 144 e.u. to + 147 e.u.) observed for this sorbent-sorbate system were also higher than those noticed in other adsorption systems studied. This indicates that the adsorbed bacteria have relatively less restriction in the presence of peptone than they have in the presence of other chemical sorbates (NaCl and SLS) studied. The bacterial adsorption is spontaneous in the presence of peptone, since ΔF^{o} values observed for this system were negative (- 18.50 to - 21.00 kcal·mole^{-1}).

Mendon Silt Loam + S. aureus + Sodium Chloride

Isotherms

Appendix L shows the complete set of isotherms obtained for Mendon silt loam - S. aureus - NaCl system at 10C, 20C, 27C, and 37C. A summary of isotherm results, α, X_{max}, and R^2 is presented in Table 1, along with the results of other system studied. The R^2 values (Table 1) were .543, .983, .669, and .959 for 10C, 20C, 27C, and 37C, respectively. The data in Table 1 show that X_{max} values observed for this system were higher than those observed in the

competitive adsorption systems discussed earlier. This indicates that NaCl does not inhibit the bacterial adsorption, but on the contrary promotes the cell uptake. This could possibly be due to the surrounding of soil particles by the swarm of Na^+ ions, thus creating a positively charged surface on the edges of the soil particles. This altered condition of the soil might have aided in increased bacterial uptake, since bacterial cells are of amphoteric nature (i.e. the individual cell possesses a positive as well as a negative charge).

Thermodynamic analysis

Table 1 shows the α values observed for this system along with the results of other systems studied. These α values are plotted against 1/T in accordance with Equation 23, in Figure 20. The measurement of slope of Figure 20 curve yields a ΔH^o value of + 23.0 kcal·mole^{-1}. The ΔS^o values (Table 1) were found to be +138.0 e.u. at all the experimental temperatures (10C, 27C, and 37C) except it was + 141.0 e.u. at 20C. The ΔF^o values calculated using Equation 16 ranged from - 16.0 to - 19.80 kcal·mole^{-1}.

The observed ΔH^o (+ 23.0 kcal·mole^{-1}) for this system indicates that the adsorption of bacteria in the presence of NaCl is relatively much more endothermic than it is in the non-competitive system. As can be seen from the results in Table 1, ΔS^o value

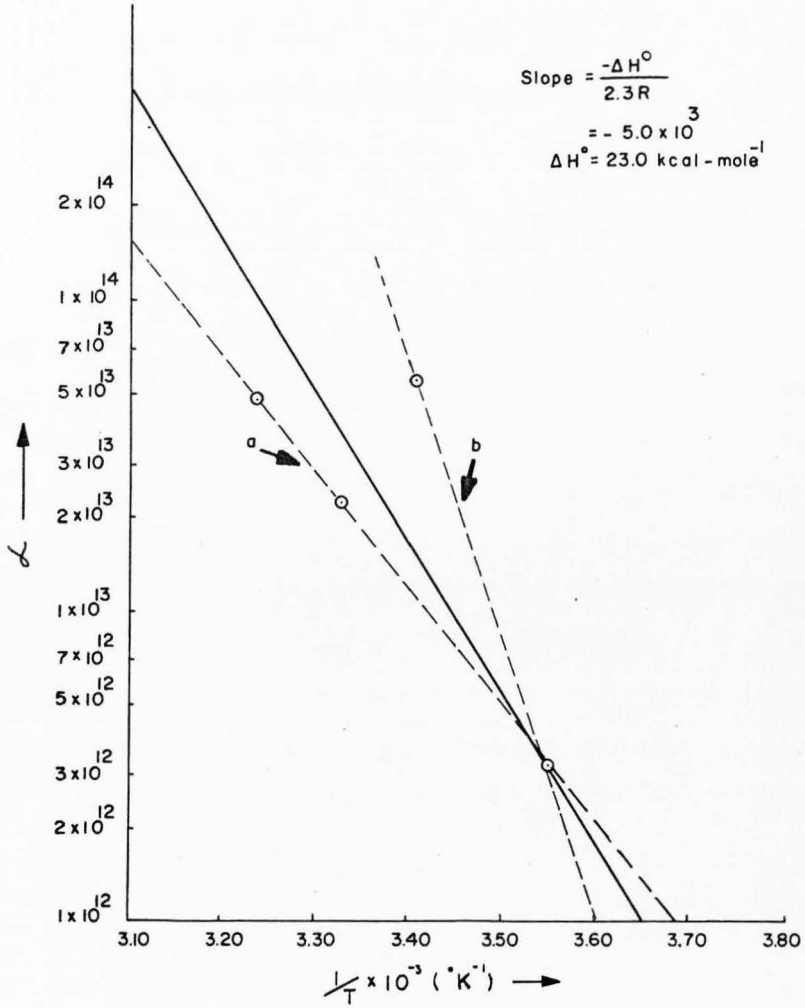

Figure 20. Evaluation of standard state enthalpy, ΔH°, for Mendon silt loam soil-S. aureus-NaCl adsorption system, using van't Hoff's equation.

(+ 138.0 e.u.) was also higher than that observed in non-competitive system (+ 92.0 e.u.), suggesting that adsorbed bacteria have relatively less restriction in the presence of NaCl than they have in the non-competitive system. The negative ΔF^{o} values (- 16.0 to - 19.80 kcal·mole^{-1}) observed for this system indicate that the bacterial adsorption in the presence of NaCl is spontaneous.

Errors

Figures 19 and 20 show noticeable scatter in points which raises some doubt as to the position of the best fit curve. The experimental temperature span of 10 - 37C is very narrow for thermodynamic work. Curve fitting to experimental points is much more sensitive to errors with such narrow temperature band. It can also be noted that only four points are used in fitting the curves.

The values in Table 1 are derived from "eye" fits as represented by the solid lines in Figures 17-20. To put the range of uncertainty in a better perspective the dashed lines "a" and "b" (Figures 19 and 20) were drawn to represent the lower and upper bounds enveloping the possible fits using the four data points. The values of thermodynamic functions resulting from the envelope boundaries are given in Table 1A.

It is difficult to make definitive statements in comparing the influence of chemicals because of the span of the envelopes (Figures 19 and 20). However, it can be stated that the values reported are probably in correct logarithmic range--which is significant. The "nominal fits" reported in Table 1 probably represent trend though it would be risky in reading too much into the differences in ΔH^{o} and ΔS^{o} reported. It might also be pointed out that despite deficiencies it appears that thermodynamic functions can be defined even as well as indicated in Figures 17-20 and Table 1A, in view of some of the uncertainties concerning bacterial count techniques.

SUMMARY AND CONCLUSIONS

1. The objective of this investigation was to delineate the thermodynamics of competitive adsorption. This was done using an experimental system consisting of Mendon silt loam as the adsorbent, S. aureus as a common adsorbate and NaCl, SLS, and peptone as competitive adsorbates.

2. The toxicity levels of SLS and NaCl to S. aureus were found to be greater than .05 gram per liter (Figure 8) and 100 grams per liter (Figure 10), respectively. Peptone did not show toxic effect on S. aureus up to the concentration of 30 grams per liter (Figure 9). It was necessary to determine the toxicity of these chemicals since the technique used was a viable cell count. All the toxicity experiments were conducted only at 27C.

3. Based on the experimental results, the selected competitive levels of SLS, peptone, and NaCl were .05 gram (Figure 8), 3.8 grams (Figure 14), and 30 grams (Figure 16), per liter, respectively. These levels were below their threshold toxic concentrations mentioned above. All the bacterial adsorption experiments were conducted using these concentrations of chemical sorbates.

4. The bacterial adsorption on soil both with and without chemical competitor followed Langmuir type isotherms (Appendices

I, J, K, and L). Isotherm parameters such as α, X_{max}, and R^2 were obtained by least square regression analysis using linear transformation of Langmuir isotherm (Equation 24). These results for all the adsorption systems studied are summarized in Table 1.

5. Evaluation of ΔH^o was accomplished by a plot of log α against the reciprocal of absolute temperature (Figures 17, 18, 19, and 20). The measured slope ($-\Delta H^o/2.3R$) of this plot allowed the calculation of ΔH^o. The ΔS^o and ΔF^o were calculated by Equation 23 and Equation 16, respectively.

6. Observed positive ΔH^o values (Table 1) indicate that the bacterial uptake in both competitive and non-competitive environments is endothermic. Bacteria and soil both have a net negative charge. A positive ΔH^o is attributed to the repulsive reaction between the bacteria and soil particles during the process of adsorption.

7. Relatively higher ΔH^o values (Table 1) were obtained using peptone and NaCl as competitive sorbates. These values were 24.0 kcal·mole^{-1} and 23.0 kcal·mole^{-1} for peptone and NaCl, respectively, suggesting that the bacterial uptake is relatively much more endothermic in the presence of these chemicals. The lower ΔH^o (-6.720 kcal·mole^{-1}) observed in a system with SLS shows that the bacterial adsorption on soil in the presence of SLS is relatively less endothermic.

8. Peptone closely resembles tryptone; tryptone has been found to desorb virus particles from carbon (Cookson and North, 1967). This suggests that peptone could possibly desorb bacteria from soil. To overcome the desorbing action of peptone, some additional amount of energy might be required. This could have resulted in a relatively high positive ΔH^{o} for the bacterial uptake in the presence of competitive concentration of peptone.

9. Sodium lauryl sulfate is an active surfactant. It is possible that SLS could have combined with bacteria, forming a SLS · bacteria complex, and because of its surfactant property the entire complex might have been adsorbed on soil. This could have favored the cell uptake, causing a relatively lower positive ΔH^{o} for bacterial adsorption reaction in the presence of SLS.

10. In all the sorbent-sorbate systems, observed ΔS^{o} values were positive (Table 1). The increase in entropy due to solvation may be greater than the decrease in entropy due to adsorption could have resulted into a net positive entropy change for the bacterial adsorption reaction (for reaction see Equation 13).

11. The ΔF^{o} values (Table 1) for all the adsorption systems were negative, indicating that the bacterial adsorption in both competitive and non-competitive environments is spontaneous. The $T\Delta S^{o}$ term is the major contributor for the negative values of free energy, since all observed ΔH^{o} values are positive (Table 1).

12. It can be proposed that when surfactants like SLS are introduced into the bacterial adsorption system, where soil is the adsorbent, surfactants will favor the bacterial uptake on soil. Relatively less energy might be required for the uptake of bacteria in the presence of competitive concentrations of such kinds of surfactants. Comparatively higher amounts of energy might be needed for the bacterial adsorption in the presence of compounds like peptone and NaCl. The bacterial uptake on soil may be spontaneous in the presence of such kinds of chemicals.

13. The bacterial adsorption, from suspension to soil, is inhibited in the presence of chemicals like SLS and peptone; and is promoted in the presence of chemicals like NaCl (Table 1).

14. The suspended bacteria in groundwaters will travel farther through the soil in the presence of chemicals like peptone and SLS than they will in the absence of such chemicals.

15. The suspended bacteria in groundwaters will travel shorter distance through the soil in the presence of chemicals like NaCl than they will in the absence of such chemicals.

Note that all the above conclusions imply to the following conditions:

a. specific viable bacterium (S. aureus),

b. short range of temperature (10C to 37C), and

c. certain textured soils (silt loam).

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APPENDICES

Appendix A

Thermodynamic Derivations

Relationship between standard state free energy, ΔF^{o}, and the equilibrium constant α

Consider the following adsorption reaction.

$$\text{sorbent} + \text{sorbate} \rightarrow \text{sorbent}\cdot\text{sorbate (complex)} \quad . \quad . \quad (25)$$

Designating X as sorbent, C as sorbate, and $\overline{X}$ as a sorbent·sorbate complex, Equation 25 can be rewritten,

$$X + C \rightarrow \overline{X} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

The equilibrium for this reaction (Equation 26) can be expressed as,

$$\alpha = \frac{\overline{X}}{X \cdot C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

where α is equilibrium constant, which is also related to standard state free energy by equation (Laidler, 1965),

$$\alpha = e^{-\Delta F^{o}/RT} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

Equating Equations 27 and 28, the following expression can be obtained,

$$\alpha = \frac{\overline{X}}{X \cdot C} = e^{-\Delta F^{o}/R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

or

$$\Delta F^{o} = -RT \ln \frac{\overline{X}}{X \cdot C} = RT \ln \alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

The Equation 30 indicates that there is a direct relationship between the standard state free energy and the equilibrium constant.

Derivation of Gibb's-Helmholtz equation

The standard state free energy is defined as

$$\Delta F^{o} = - RT \ln \alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

Differentiating with respect to temperature Equation 31 yields,

$$\frac{- d[\Delta F^{o}]}{dT} = R \ln k + RT \frac{d \ln k}{dT} \quad . \quad . \quad . \quad . \quad . \quad (32)$$

Recalling the relation, $dF = Vdp + SdT$ and differentiating with respect to T, the following is obtained,

$$\left(\frac{dF^{o}}{dT}\right)_{p} = - S^{o} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

Substracting initial state from final state condition gives

$$- \Delta S^{o} = - (S^{o}_{2} - S^{o}_{1}) = \left(\frac{dF^{o}_{2}}{dT}\right)_{p} - \left(\frac{dF^{o}_{1}}{dT}\right)_{p}$$

$$= \left[\frac{d (\Delta^{o} F}{dT}\right]_{p} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (34)$$

Now, if it is recalled that for an isothermal process

$$\Delta F^{o} = \Delta H^{o} - T\Delta S^{o} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

Substituting for ΔS^{o} (Equation 34) in Equation 35 yields:

$$\Delta F^{o} = \Delta H^{o} + T \left[\frac{d (\Delta F^{o})}{dT}\right]_{p} \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$

which is the Gibb's-Helmholtz equation.

Appendix B

Bacterial Adsorption Data Processing Programs

Two appropriate programs were written to process the bacterial depletion data and the equilibrium data. These programs are described below.

BACTXT

Figure 23 is a program listing of BACTXT as programmed in Fortran V, and run on the Univac 1108. Following the program listing is a listing of input data cards (Figure 21C) used along with the program. The deck set-up along with the input data cards is illustrated diagramatically in Figure 22. Figure 24 (24A, 24B, 24C, and 24D) is the sample of program output. Figures 24B and 24C, and Figure 24D are two options of program output; either or both options may be specified. BACTXT program:

1. Calculates the cell concentrations, both in the solution phase, C, and in the adsorbed phase, $\overline{X}$, measured at selected sampling time intervals (Figure 24A).
2. Produces a curve showing the bacterial uptake with time (Figure 24B).

3. Yields a curve showing the bacterial depletion with time (Figure 24C).
4. Gives both bacterial uptake and bacterial depletion curves on the same plot (Figure 24D).

ALPHAB

Figure 27 is a program listing of ALPHAB as programmed in Fortran V, and run on the Univac 1108. Following the program listing is a listing of input data cards used along with the program (Figure 25B). Figure 28 (28A, 28B, and 28C) is the sample of program output. ALPHAB:

1. Calculates α, X_{max}, and R^2 (Figure 28A), from the equilibrium data, and
2. Produces linearized Langmuir isotherm (Figure 28B) and conventional Langmuir isotherm (Figure 28C) plots.

BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION OF DATA

(A) FIXED DATA FOR RUN

Variable Name	Field	FORTRAN STATEMENT
DATE	2A4	01/30/70
HOUR	I12	1500
RUN	I8	27
TYPE	2A4	20PTNACL
SBATE	7A2	STAPH-AUREUS
STRAIN	2A5	FDA-209
SBENT	3A6	MENDØN SILT LØAM
SKIND	3A6	CØMPETITIVE
APPCON	F12.0	75000000.
SAMVOL	F5.1	1.
SOLVOL	F10.1	200.
ODWT	F5.1	1.
N	I6	6
TEMP	F6.1	27.
VTZERO	F6.1	170.

Figure 21A. IBM coding sheet for recording a fixed data for run.

Initial Dave

BACTERIAL ADSORPTION EXPERIMENTS – COLLECTION OF DATA

(A) VARIABLE DATA FOR RUN

DO NOT PUNCH

I/J	DATE	CLOCK TIME	TSUM(I) F12.3	DILNO(I) F12.3	PIPVOL(I) F12.3	PLACNT(I,1) / PLACNT(I,2) F12.3/F12.3	VALOBS(I) F12.3
1/1			0.	3.	1.	70.	1.
/2						0.	
2/1			5.	3.	1.	40.	1.
/2						0.	
3/1			15.	3.	1.	30.	1.
/2						0.	
4/1			30.	3.	1.	15.	1.
/2						0.	
5/1			45.	3.	1.	35.	1.
/2						0.	
6/1			60.	3.	1.	25.	1.
/2						0.	
7/1							
/2							
8/1							
/2							
9/1							
/2							
10/1							
/2							
11/1							

Figure 21B. IBM coding sheet for recording a variable data for run.

Initial Dave

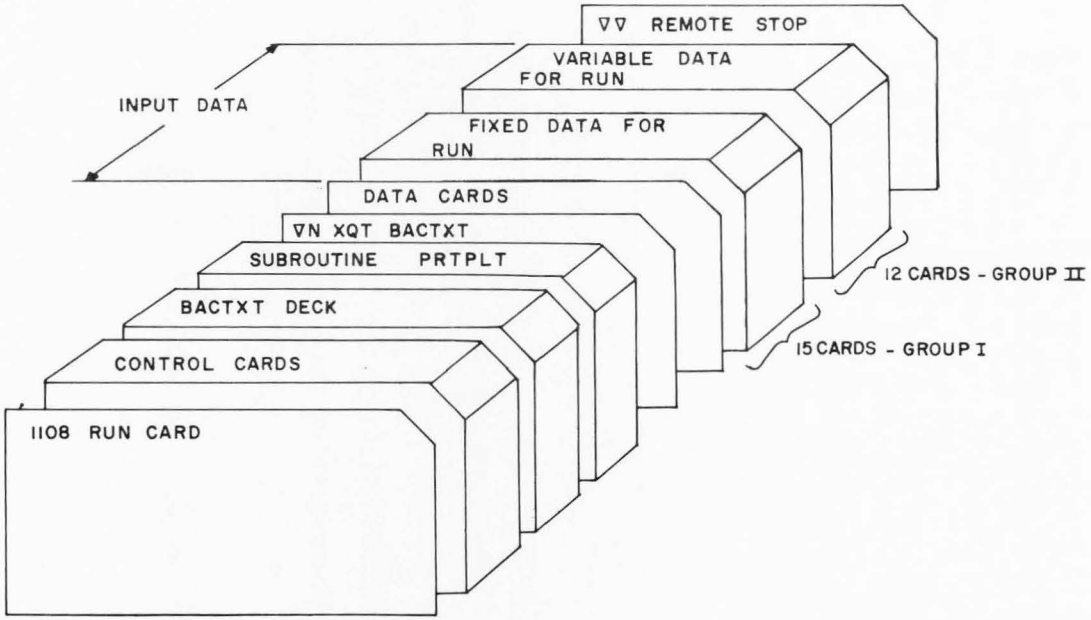


Figure 22. Deck set-up for BACTXT data input.

```
C     PROJECT WG-62 BACTERIAL ADSORPTION ON SOILS
C     IF RUN IS *CONTROL*, ODWT = 100
C     VTZERO IS VOL PRIOR TO ADDITION OF SORBENT. C(I) MUST BE ADJUSTED
C     TO SOLVOL BY FACTOR VTZERO/SOLVOL
C     CALCULATION OF XBAR VS TIME FROM RAW DATA
      DIMENSION  TSUM(20),DILNO(20),PIPVOL(20),                VALOBS(20),
     2AVGPC(20),DILFCT(20),C(20),XBAR(20),PLACNT(20,10)
      DIMENSION DATE(2),TYPE(2),SRATE(3),STRAIN(2),SBENT(3),SKIND(3)
      INTEGER HOUR,RUN
      READ(5,895)NXTBAR
  895 FORMAT(I5)
    1 READ(5,16)DATE,HOUR
   16 FORMAT(2A6 ,/I12)
      IF(HOUR .GT.2600) GO TO 99
      READ(5,15)                RUN,TYPE,SBATE,STRAIN,SBENT,SKIND,APPCON,SAMV
     2OL,SOLVOL,ODWT,N,TEMP,VTZERO,(TSUM(I),DILNO(I),PIPVOL(I),PLACNT
     3(I,J),VALOBS(I),PLACNT(I,2),I=1,N)
   15 FORMAT ( I8/2A6/3A6    /2A6     /3AF/3A6/F12.0/F5.1/F10.1/F5.1/I6/F6
     2.1/F6.1/15F12.3/6X,F12.3))
      VOLPM = SOLVOL
      TSRATF = 0.
      DO 25 I =1,N
      VOLREM = VOLPM - SAMVOL
      VOLPM = VOLREM
      AVGPC(I) =  (PLACNT(I,1) + PLACNT(I,2))/VALOBS(I)
      DILFCT(I) = (10.**(2.*DILNO(I)))/PIPVOL(I)
      C(I) = AVGPC(I)*DILFCT(I)
      TSRATR = TSRATR + SAMVOL*C(I)
      TSRATF = TSRATR
      CITM1 = AVGPC(1)*DILFCT(1)
      C(1) = CITM1*VTZERO/SOLVOL
      IF(ODWT .GT. 50.) GO TO 23
      XBAR(1) = C(1)*SOLVOL - C(1)*VOLREM - TSBATR )/ODWT
      GO TO 25
   23 XBAR(1) = 0.
   25 CONTINUE
      XBAR(1) = 0.
      WRITE(6,100) DATE,SBATE,SOLVOL,HOUR,STRAIN,ODWT,RUN,SRENT,TYPE,SKI
     2ND,APPCON,TEMP,SAMVOL
  100 FORMAT(1H1/27X*TABLE 2  BACTERIAL ADSORPTION EXPERIMENTS - COLLECT
     2ION AND REDUCTION OF DATA*//20X*DATE*,2X,2A6,12X*SORBATE*,2X,3A6,1
     33X*SOL. VOL.*,F10.1,2X*ML*/20X*HOUR*,17,1X*HRS*,20X,2A6,19X*SORBEN
     4T WT. (GM)*,F5.1,2X*SM*/20X*RUN*,17,20X*SORBENT*,3A6/20X*TYPE OF R
     5UN*,2X,2A6,18X,3A6/50X,*INITIAL CONC (SPECT READ)*,F12.0,2X*BUGS/M
     6L*/50X*TEMP*,F6.1,2X*DEG. C.*/50X*SAMPLE VOL.*,F5.1,2X*ML*///)
      WRITE(6,102)
  102 FORMAT ( 5X*ELAPSED*,3X*NO. OF DIL.*,5X*PIPET VOL.*,6X*FILTER*,7X*
     2NO. OF*,6X*AVG FILTER*,5X*DIL. FACT.*,4X*SOLUTION*,7X*XBAR*/ 6X*TI
     3ME*,5X*OF 99 ML FA.*,3X*DEL. TO PLATE*,3X*PLATE COUNT*,3X*VALID OB
     4S.*,9X*PLATE COUNT*,21X*CONC.*/ 6X*(MIN)*,22X*(ML)*,9X*(BUGS/PLATE
     5)*,15X*(BUGS/PLATE)*,18X*(BUGS/ML)*,4X*(BUGS/GM)*/)
      WRITE(6,101) (TSUM(I),DILNO(I),PIPVOL(I),PLACNT(I,1),VALOBS(I),AVG
     2PC(I),DILFCT(I),C(I),XBAR(I),PLACNT(I,2),I=1,N)
  101 FORMAT (   F11.1,4X,F7.0,4X,F12.1,4X,F12.0,F11.0,4X,F12.0,4X,F12.0
     2,1X,F13.0,F14.0,4X,F12.0/)
      IF(XBAR(1) .EQ. 1100.) GO TO 99
C     BEGIN OPERATION OF PLOTTER TO PLOT XBAR VS TSUM
C     STEP 1 ESTABLISH DIMENSIONS OF PLOT PAPER
      LM = N-1
      FOUTLX = (XBAR(1) + XBAR(LM))/2.
      FOUTLC = (C(1) + C(LM))/2.
      CALL IPLOT(11.0,17.0)
C     STEP 2 PROVIDE MAILING INSTRUCTIONS
      CALL SYMBOL(.2,.2,.2,13,-94,0.0)
      PLOT AT UNIV., LOGAN, UTAH 84321  SEND BY FIRST CLASS MAIL.90.0,-9.0)
C     STEP 3 ESTABLISH PERMANENT ORIGIN FOR GRAPH
      CALL PLOT(1.5,2.0,-3)
C     STEP 4 ESTABLISH X-AXIS, THEN Y-AXIS - LABEL EACH
      ALX = 12.0
      ALY = 8.
      CALL SCALE (TSUM, 4., ALX,TMIN,DTIME,1)
      CALL AXIS (0.0, 0.0, 10HTIME (MIN),-10,ALX,0.0,TMIN, DTIME)
      CALL SCALE (XBAR, 4., ALY, XRAMN, DYBAR,1)
      CALL AXIS (0.0, 0.0, 27HXBAR  (BACTERIA/GM SORBENT), 27, ALY,
     290.0, XRAMN, DYBAR)
C     STEP 5 SHOW THE EXPERIMENTS
      CALL PLOT (0.0, 0.0, 3)
      DO 401 I = 1,N
  401 CALL SYMBOL(TSUM(I), XBAR(I), 0.14, 1HX, 0.0, 1)
C     STEP 6 LABEL GRAPH
      CALL SYMBOL (3.5,-1.0, 0.20, 27HBACTERIAL ADSORPTION, 0.0, 27)
      CALL SYMBOL (1.5,-1.5, 0.10, 9HDATE, 0.0,9)
      CALL SYMBOL (3.0,-1.5, 0.10, DATE, 0.0, 12)
      CALL SYMBOL (7.5,-1.5, 0.10, 7HRUN#,0.0, 7)
      CALL NUMBER (7.5,-1.5, 0.10, RUN, 0.0,0)
      CALL SYMBOL ( 7.5,-1.5, 0.10, 6HTEMP, 0.0, 6)
      CALL NUMBER ( 7.5,-1.5, 0.10, TEMP, 0.0,3)
      CALL SYMBOL (1.5,-1.9, 0.10, 7HSORBENT,0.0, 7 )
      CALL SYMBOL (3.0,-1.9,0.10, SBENT, 0.0, 18)
      CALL SYMBOL (1.5,-2.3, 0.10, 7HSORBATE, 0.0, 7 )
      CALL SYMBOL (3.0,-2.3, 0.10, SBATE, 0.0,18)
      CALL SYMBOL (1.5,-2.7, 0.10, 6HSTRAIN, 0.0,6)
      CALL SYMBOL (3.0,-2.7, 0.10,STRAIN, 0.0, 12)
C     STEP 7 DO CALIBRATION CURVE
      CALL SCALE (C,4.,ALY,CMIN,DCONC,1)
      CALL AXIS (13.,90.0,37HSOLUTION CONCENTRATION  (BACTERIA/ML),-37,
     2ALY, 90.0,CMIN, DCONC)
C     GO BACK TO ORIGIN WITH PEN UP
      CALL PLOT (13.,0.,+3)
C     SHOW EXPERIMENTAL POINTS FOR CONC
      DO 405 I = 1,N
  405 CALL SYMBOL (TSUM(I), C(I), 0.14, 1HO, 0.0,1)
      CALL PLOT (-1.0,-1.0,-3)
      CALL FINI
  99  CONTINUE
      DATA YAXIS,4HXAIS/4HXBAR,6HMINUTE/
      SFXXIS,0
      XMINXS,
      PEN,
      YPEN,E+09
      IEND
      CALL FRIPLT(SCXY,4,TSUM,YMIN,XBAR,P,YP,YAXIS,XAXIS,IC)

      DATA ZAXIS,4HXAIS/6HCONC, 6HMINUTE/
      YPEN,E+05
      CALL FRIPLT(SCXY,4,TSUM,YMIN,C,   P,YP,ZAXIS,XAXIS,IC)
      CALL IPLOT
      STOP
      END
```

Figure 23. Program listing of BACTXT.

```
      SUBROUTINE PRTPLT(SCXX,N, X,XMIN,Y,P,YZ,YAXIS,XAXIS,IC)
C     SUBROUTINE PRTPLT FOR PLOTTING X,Y POINTS ON GRAPH.X SCALE MUST BE
C       KNOWN. Y SCALE MAX VALUE WILL BE READ AND ADJUSTED IF NOT KNOWN.
C     IF YMAX .LT. 2 TIMES INTERVAL SET. INTERVAL READJUSTED TO FIT
C     FIGURE LIMITS.
C     ARGUMENTS AS FOLLOWS
C       SCXX=SCALE FACTOR FOR X AXIS UNITS PER INCH WITH 12 INCHES
C       N=NUMBER OF X AND Y OBSERVATIONS, FROM MAIN PROGRAM
C        X=X ARRAY FROM MAIN PROGRAM-LIMIT ONE
C       XMIN=XMIN = VALUE OF X ORIGIN
C        Y=Y ARRAY FROM MAIN PROGRAM-MAYBE MORE THAN ONE.
C       P=YMIN(1)=ORIGIN OF Y AXIS. ONE YMIN(J) FOR EACH Y ARRAY
C       YZ=NYL(1)=INCREMENT OF Y AXIS. 9 INCHES
C       YAXIS= LABEL FOR Y AXIS. APPEARS TOP LEFT  LINE OF FIGURE ( A6)
C       XAXIS= LABEL FOR X AXIS  APPEARS TOP CENTER OF FIGURE ( A6)
C       IC=M(J)=INTEGER SPECIFYING MODE OF X AND Y FOR PRINTING FORMATS
C                 14 X=F FIELD, Y=E FIELD
C                 15 X=E FIELD, Y=F FIELD
C                 24 X=F FIELD, Y=E FIELD
C                 25 X=F FIELD, Y=F FIELD
C     ARGUMENTS FIXED FOR THIS SUBROUTINE BUT WHICH CAN BE VARIED TO
C     PUT MULTIPLE Y'S ON SAME FIGURE (NO SCALES PRINTED) AND TO LIST
C     TRANSFORMED X AND Y'S  ARE AS FOLLOWS
C       JTEST = 0 NO X TRANSFORM, =1 LOG10
C       ITEST(J) = 0 NO Y TRANSFORM.   =1,LOG10.ONE ITEST FOR EACH Y
C          ARRAY
C       NY=NUMBER OF SEPARATE Y ARRAYS =1 NORMALLY
C       PT(J) = PLOT SYMBOL FOR EACH XY POINT. ONE FOR EACH Y ARRAY
C       NMPS=SINGLE=0 OR MULTIPLE=1 PLOTS ON SAME FIGURE. NO YSCALE IF 1
C         LP=LIST OPTION,0=NO LIST,1=TABLE GENERATED
      REAL NX,NMIN,NYL,NO
      DIMENSION NX(300),Y(300,10),A(125,60),A0(300,10),        ND(12),
     1P(60),IX(300),IY(300,10),ITEST(10),        PT(10),YMIN(10),
     2NMIS(10),NYL(10),YS(10),X(300),                M(10)
      DATA BLANK,ZERO,DASH,TICK,ORIG,PT(1)/1H ,1H0,1H-,1HT,6HORIGIN,1H+/
      DO 802 I=1,N
      NX(I)=X(I)
  802 CONTINUE
      NYL(1)=YZ
      YMIN(1)=P
      NMIN=XMIN
      JTEST=0
      NY=1
      ITEST(1)=0
      NMPS=0
      M(1)=IC
      LP=0
      Z=1.
C     ESTABLISH BOUNDRY MARKS
      DO 5 I=1,121
      DO 5 J=1, 60
      B(J)=BLANK
    5 A(I,J)=BLANK
      DO 35 J=1,55
   35 A(2,J)=TICK
      DO 65 J=1,55,6
   65 A(1,J)=DASH
      DO 31 I=3,121
      A(I,1)=DASH
   31 A(I,55)=DASH
      DO 52 I=2,121,10
   52 A(I,56)=TICK
C     SCALE X AND TRANSFORM X OR NOT
      SCLX=10./SCXX
      IF(JTEST.EQ.0) GO TO 2
      DO 1 I=1,N
      IF(NX(I).GT.10.E+19) GO TO 7
      IF(NX(I).LE.0.) GO TO 3
      NX(I)=ALOG10(NX(I))
    3 CONTINUE
    2 DO 22 I=1,N
      ITX(I)=SCLX*(NX(I)-NMIN)+2.5
      IF(ITX(I).GT.121)ITX(I)=121
      IF(ITX(I).LT.2)ITX(I)=2
   22 CONTINUE
C     DETERMINE MISSING VALUES OF Y ONLY. X MUST BE COMPLETE
      DO 4 J=1,NY
    4 NMIS(J)=0.
      NP(1)=NMIN
      DO 41 I=2,12
   41 NP(I)=NP(I-1)+SCXX
C     BEGIN Y DETERMINATION AND PLOT-PRINT-POINT-VALUES
      DO 70 J=1,NY
C     SEARCH FOR MISSING DATA AND TRANSFORM Y IF CALLED FOR
      DO 503 I=1,N
      Z=ISN(Z,Y(I,J))
      IF(Z)13,503,503
   13 NMIS(J)=NMIS(J)+1
      Y(I,J)=10.E+2
      GO TO 503
  503 CONTINUE
      IF(ITEST(J).EQ.0)GO TO 78
      DO 77 I=1,N
      IF(Y(I,J).GT.10.E+19) GO TO 77
      IF(Y(I,J).LE.0.)GO TO 77
      Y(I,J)=ALOG10(Y(I,J))
   77 CONTINUE
C     SCALE Y
   78 K=1
   87 IF(Y(K,J).LT.10.E+19) GO TO 79
      K=K+1
      IF(K.LE.N) GO TO 87
   79 YMAX=Y(K,J)
      K=K+1
      DO 10 I=K,N
      IF(Y(I,J).ST.10.E+19) GO TO 10
      IF(Y(I,J).GT.YMAX)YMAX=Y(I,J)
   10 CONTINUE
      CONVL(J)
C     CHANGES Y SCALE TO FIT DATA
      SC(YMAX-YMIN(J))/9
      IF(S.GT.C) GO TO 502
```

Figure 23. Program listing of BACTXT (continued).

```
      IF(S.LT.E*.232222222) GO TO 603
      GO TO 86
C     REDUCES Y SCALE AND SETS NEW INTERVAL C IF YMAX TOO LOW ON SCALE
  603 DO 6611=10,103,10
      R=C/11
      IF(S.GT.E**.22222222.AND.S.LT.S) GO TO 604
C     IF SCALE REDUCED TOO FAR, EXPAND AGAIN
      IF(S.GT.P) GO TO 605
   66 CONTINUE
  635 C=P
C     INCREASES SCALE AND SETS NEW INTERVAL C
  602 DO 19 I=2,100
      P=I*C
      IF(S.LE.P) GO TO 604
   19 CONTINUE
  604 S=P
   86 SCLY=6.0/C
      IF(YMP.NE.0)GO TO 21
      P(1)=YMIN(J)
      DO 20 JJ=7,55,6
   20 A(JJ)=P(JJ-6)+C
      YS(J)=C
   21 DO 15 I=1,N
      IF(Y(I,J).GT.10.E+19) GO TO 11
      IY(I,J)=SCLY*(Y(I,J)-YMIN(J))+1.5
      IF(IY(I,J).GT.55)IY(I,J)=55
      IF(IY(I,J).LT.1)IY(I,J)=1
      IX=IX(I)
      IY=IY(I,J)
      IF(IX.EQ.2) GO TO 61
      IF(IY.EQ.1.OR.IY.EQ.55) GO TO 62
   11 A0(I,J)=BLANK
      GO TO 14
   61 A0(I,J)=TICK
      GO TO 14
   62 A0(I,J)=DASH
   14 IF(Y(I,J).GT.10.E+19) GO TO 15
      A(IX,IY)=PT(J)
   15 CONTINUE
      IF(YMP.NE.0)GO TO 68

C
C     PLOT FIGURE X VS. ONE Y
C
      WRITE(6,102)YAXIS,YS(J),XAXIS,N
  102 FORMAT(1H1,A6,1X,F10.3,' UNITS/INCH.',20X,A6,18X,'NOBS =',I5)
      DO 85 L=1,55
      IF(N(56-L).EQ.BLANK) GO TO 81
      IF(M(J).EQ.15.OR.M(J).EQ.25) GO TO 42
  80  WRITE(6,103)B(56-L),(A(I,56-L),I=1,121)                    Y=E
      GO TO 85
   42 WRITE(6,1101)B(56-L),(A(I,56-L),I=1,121)                   Y=F
      GO TO 85
   81 WRITE(6,104)(A(I,56-L),I=1,121)                            Y=
   85 CONTINUE
  103 FORMAT(1X,E8.4,121A1)                                      Y=E
  110 FORMAT(1X,F8.3,121A1)                                      Y=F
      WRITE(6,104)(A(I,56),I=1,121)                              Y=
  104 FORMAT(9X,121A1)                                           Y=
```

```
      IF(M(J).EQ.24.OR.M(J).EQ.25) GO TO 43
      WRITE(6,1031)B(57),I=1,121)                                X=E
      GO TO 64
   43 WRITE(6,1031)B(58),I=1,121)
  103 FORMAT(1H  ,E9.3,121A1)                                    X=F
  110 FORMAT(1H  ,F9.3,121A1)                                    X=
   64 IF(I.N=1
      IX=IX(I)
      IY=IY(I,J)
   67 IF(IY-IY)=ADD(I,J)
      IF(I.LE.100)GO TO 70
      IF(J.LE.NY)GO TO 69
      GO TO 70
   68 IF(J.LE.NY)GO TO 70

C
C     PRINT TRANSFORMED DATA IN TABLE
C
   69 WRITE(6,1211)SE(J),*
  121 FORMAT(1H1,*MULTIPLE PLOT DATA*,2X,* X AXIS ONE INCH =*,F6.1,*.*,8X,
     1* SCALE =*,F5.1)
      WRITE(6,1221)(P(I),I=1,NY)
  122 FORMAT(1X,A6,6(1P,E12.5))                                  Y=E
      WRITE(6,1231)(A(I,56),I=1,NY)
  123 FORMAT(1X,'H ORIGIN=',1PE12.5,'  DELTA=',1PE12.5)
      WRITE(6,1241)(M(I),I=1,NY)
  124 FORMAT(1H ,'MISSING=',8X,121I1)
  169 GO TO (1,2),I
   86 WRITE(6,125)X(1),(Y(I,K),K=1,NY)
  125 FORMAT(F9.0,1X,6(1PE12.5))                                 X=E Y=E
      IF(N.EQ.0)GO TO 71

C
      PRINT FIGURE X VS. UP TO 10 Y'S BUT X AXIS NOT LABELED
C
      WRITE(6,1241)B(53),I=1,NY)
  124 FORMAT(1H1,*MULTIPLE   Y PLOT*,17(8X,A2))
      DO 30 L=56,1,-1
   30 WRITE(6,1041)B(L),(A(I,L),I=1,121)
      WRITE(6,1041)B(1),(A(I,1),I=1,121)
      IF(M(J).EQ.24.OR.M(J).EQ.25) GO TO 177
      WRITE(6,1041)B(57),I=1,121)
      GO TO 179                                                  X=E
  177 WRITE(6,1031)B(57),I=1,121)                                X=F
  179 DO 31 I=1,N
      DO 31 K=Y,1,-1
      IY=IA(I)
      IX=IY(I,K)
   31 IY=IY-IX*ADD(I,K)
   70 CONTINUE
      RETURN
      END
```

Figure 23. Program listing of BACTXT (continued).

Figure 24A. Output from BACTXT-tabuler printout.

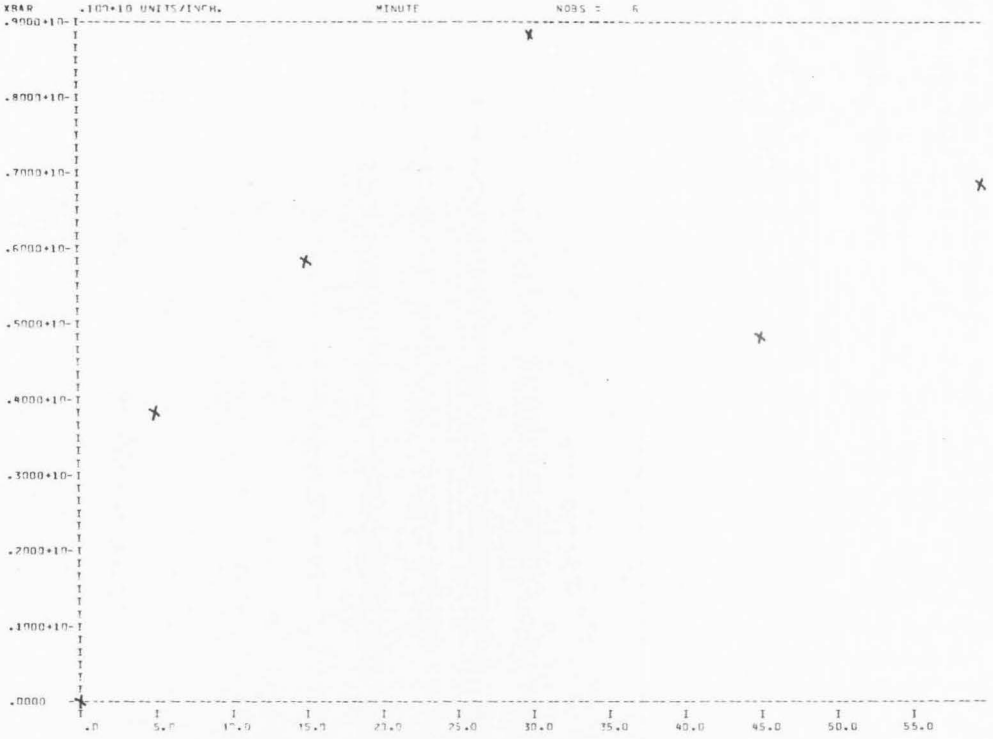


Figure 24B. Output from BACTXT-Bacterial uptake curve.

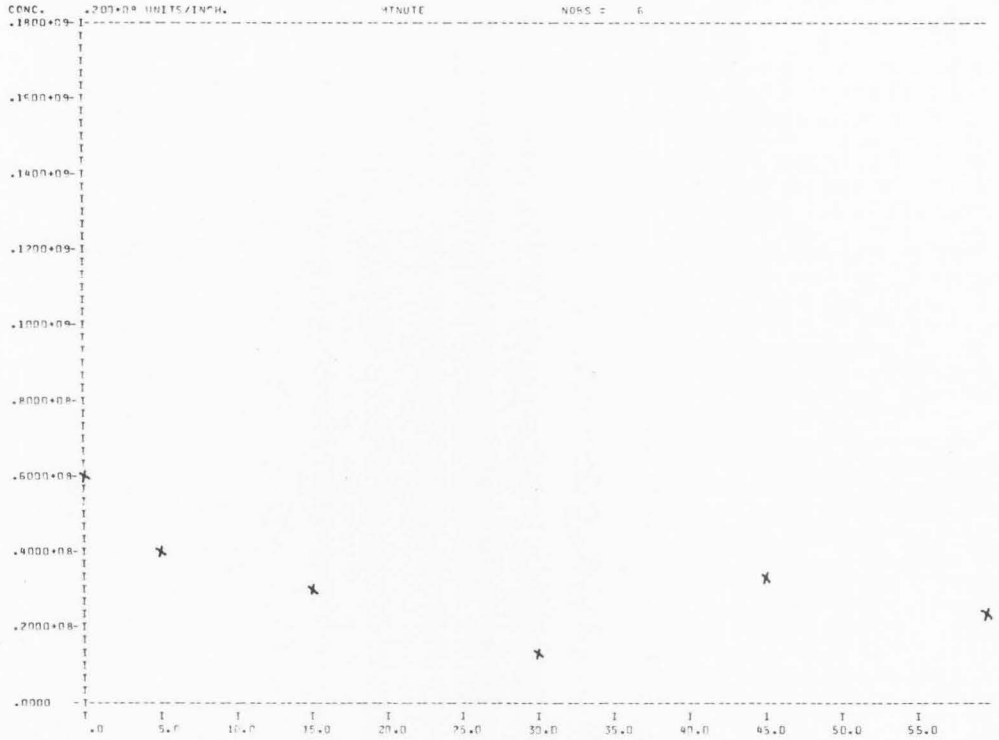


Figure 24C. Output from BACTXT-Bacterial depletion curve.

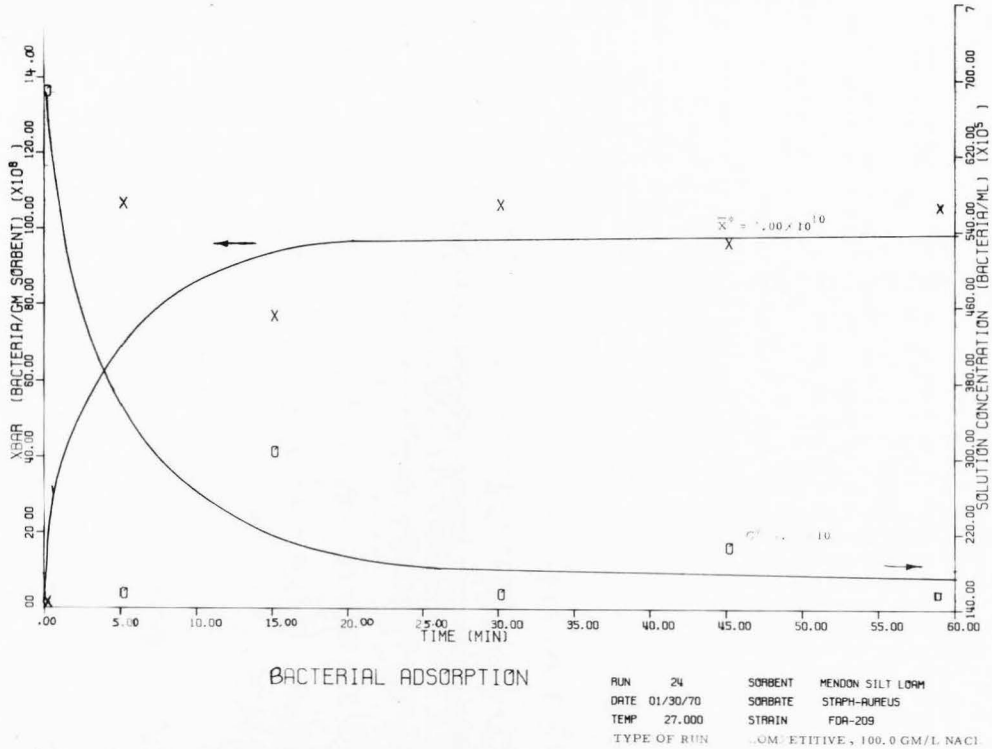


Figure 24D. Output from BACTXT-Bacterial depletion and uptake curves by GBR plot.

BACTERIAL ADSORPTION
DERIVATION OF ALPHA AND XMAX FROM REG. ANAL. OF LINEARIZED ISOTHERM

Variable Name	Field
NRUNS	(I6)
SBATE	(7A2)
STRAIN	(2A6)
SBENT	(3A6)
SKIND	(3A6)
TEMP	(F6.1)

NRUNS = 6
SBATE = STAPH-AUREUS
STRAIN = FDA-209
SBENT = SOIL
SKIND = MENDON SILT LOAM
TEMP = 37.

RUN(I) (I10)	SDATE(I) (2A4) mo. day yr.	CSTAR(I) (E12.2)	XBARST(I) (E12.2)
1	01/16/70	8.00E07	2.50E10
2	01/16/70	5.50E07	2.50E10
3	01/16/70	3.30E07	2.50E10
4	01/16/70	2.00E07	2.40E10
8	01/20/70	15.00E07	2.80E10
9	01/20/70	10.00E07	2.50E10
	/ /	. E	. E
	/ /	. E	. E
	/ /	. E	. E
	/ /	. E	. E
	/ /	. E	. E
	/ /	. E	. E
	/ /	. E	. E
	/ /	. E	. E

Figure 25A. IBM coding sheet for recording the equilibrium data.

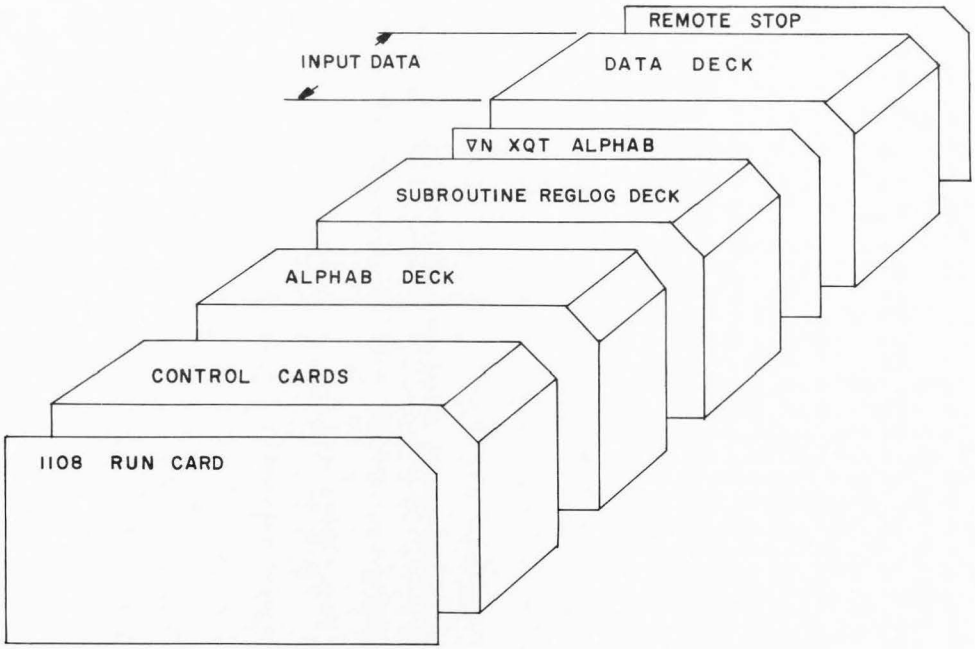


Figure 26. Deck set-up for ALPHAB data input.

```
C     CALCULATION OF ALPHA AND XMAX FROM CSTAR AND XBARSTAR
C     PROJECT WG-57 PATTERTAL ADSORPTION ON SOILS
      DIMENSION CSQUM(40)
      DIMENSION CSTAR(40),XBARST(40),IRUN(40), CSOXST(40)
      DIMENSION SDATE(40,2),          SFATE(3),STRAIN(2),SRENT(3),SKIND(3)
      DATA IDX,IDY/4HCST,4HXBST/
     2 STATES,13NRUNS,5HATE,STRAIN,SRENT,SKIND,TEMP,      (IRUNS(I),SDAT
     2E(I,1),SFATE(I,2)),  CSTAR(I),XBARST(I),I=1,NRUNS)
     13 FORMAT(I6/3A6/2A6/3A6/3A6/FB.1/(I10,2A4,2E12.2))
      DO 705 I = 1,NRUNS
      CSQUM(I) = CSTAR(I)
705   CONTINUE
      IRUNLO = IRUNS(1)
      IRUNHI = IRUNS(NRUNS)
      NNS=3
      NPR=1
      NTX=1
      NTY=1
      CX=1
      CY=1
      DO 16 I=1,NRUNS
      CSOXST(I)=CSTAR(I)/XBARST(I)
   16 CONTINUE
      M = NRUNS
      CALL REGLOGM,NP,NPR, IDX, IDY,CSTAR,CSOXST,NTX,NTY,CX,CY,YINCEP,
     2SLOPE,2,0,959)
C     CSTR=IDX+COXST=IDY,CSTR=Y,COXST=Y,YINCEPT=A,SLOPE=B
      XMAX=1./SLOPE
      ALPHA=1./EXP(YINCEP*XMAX)
      WRITE(6,953)
953   FORMAT(1H1,7X////2X,*PETER*INATTON OF ALPHA AND XMAX BY REGRESSION AN
     2ALYSIS OF LINEARIZED LANGMUIR ISOTHERM*)
      WRITE(6,954)SFATE(1),1),SDATE(1,2),SFATE,IRUNLO,IRUNHI,STRAIN,SBENT
     2,SKIND,TEMP,B,B5G,YINCEP,SLOPE,ALPHA,XMAX
954   FORMAT(1HO///4BX*DATE OF RUN I = *,2A4, 7X*SORBATE*,2X,3A6/40X*RUN
     1S*,I6,2X*TO*,I6,2?X,2A6/21X*SORPENT*,3AE/28X,3A6/24X*TEMP*,F6.1,
     2?X*DEG. CENT.*////
     3?X**REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS*//45X*R =
     4*,F6.4 /45X*SQ =*,F6.4 /19X**INTERCEPT = 1/(ALPHA*XMAX) =*,E12.6/
     529X*SLOPE OF BEST FIT =*,E12.6/41X*ALPHA =*,E12.6/42X*XMAX =*,E12.
     66///35X*BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS*//45X*RUN
     7S*,5X*DATE EXP BEGUN*,2X*C*,6X*XBAR*,5X*C/XBAR*)
956   WRITE(6,955)(IRUNS(I),SDATE(I,1),SDATE(I,2),  CSTAR(I),XBARST(I),C
     2SOXST(I),I=1,NRUNS)
955   FORMAT(2X,I5,6X,2A4,E14.5,E12.5,E15.5)
C     ORGIN OPERATION OF PLOTTER TO PLOT (CSTAR/XBSTAR) VS CSTAR
C     STEP 1 ESTABLISH DIMENTIONS OF PLOT PATER
      CALL IOPLOT(14.0,17.0)
C     STEP 2 PROVIDE MAILING INSTRUCTIONS
      CALL SYMBL4(0.,2.0,0.17,94HMAIL TO D. W. HENDRICKS, UWRL, UTAH
     DSTATE UNIV., LOGAN, UTAH 84321  SEND BY FIRST CLASS MAIL,90.0,94)
C     STEP 3  ESTABLISH PERMANENT ORGIN FOR GRAPH.  THIS IS DONE BY (-1
      CALL PLOT(1.5,2.0,-3)
C     STEP 4  ESTABLISH X-AXIS, THEN Y-AXIS -LABEL EACH AXIS
      ALX = 10.1
      ALY = 8.0
      KRUNS = NRUNS + 1
      CSTAR(KRUNS) = 0.
      CSOXST(KRUNS) = 0.
      CALL SCALE(CSTAR,ALX,KRUNS,1)
      CALL AXIS (0.0,0.0,15HCSTAR (MG/G/ML),-15,ALX,0.0,CMIN,DSTAR)
      CALL SCALE(CSOXST,ALY,KRUNS,1)
      CALL AXIS(0.0,0.0,14HCSTAR/XBARSTAR,14,ALY,90.0,CSMIN,DCSX)
C     STEP 5 SHOW THE EXPERIMENTAL POINTS
      CALL PLOT(0.,+0.,3)
      DO 801 I = 1,NRUNS
801   CALL SYMBL(CSTAR(I),CSOXST(I),0.10,1HX,0.0,-1)
C     STEP 6 PLOT THE BEST FIT CURVE
      YZERO = (YINCEP-CMIN)/DCSX
      XOI = .0*ALX
      XOISI = .R*ALX*DSTAR
      XMAX = YZERO + (SLOPE*XOISI)/DCSX
      CALL PLOT(0.,0.,3)
      CALL PLOT(0.,YZERO,3)
      CALL PLOT(XOI,YMAX,2)
      CALL PLOT(0.,0.,3)
C     LABEL GRAPH WITH APPROPRIATE IDENTIFICATION INFORMATION
      CALL SYMBL4(0.,1.,.2,.CHINSIERTIAL ADSORPTION EXPERIMENTS - LI
     1NEARIZED LANGMUIR ISOTHERM,0.,54)
      CALL SYMBL4(0.,-.1,.35,.2,1HNUMBER,0.,8)
      CALL NUMBR1(0.,-.1,.35,6.,1,IRUNLO,0.,0)
      CALL SYMBL4(0.,-.1,.50,.2,1HTO,0.,2)
      CALL NUMBR1(0.,-.1,.65,6.,1,IRUNHI,0.,0)
      CALL SYMBL4(0.,-.1,.75,.2,11,0.4HTEMP,0.,5)
      CALL NUMBR1(0.,-.1,.9,6.,1,TEMP,0.,0)
      CALL SYMBL4(0.,-.1,.5,0.,13,5HDEGREE,0.,7)
      CALL SYMBL4(0.,-.1,.75,0.,13,5HCENT,0.,5)
      CALL SYMBL4(0.,-.1,.5,0.,11,7HCORRATE,0.,7)
      CALL SYMBL4(0.,-.1,.5,0.,10,5HSTATE,0.,5)
      CALL PLOT(-1.,-1.,-3)
      CALL EXIT
C     ORGIN OPERATION OF PLOTTER TO PLOT XBAR* VS C* (LANGMUIR ISOTHERM)
C     STEP 1 ESTABLISH DIMENTIONS OF PLOT PATER
      CALL IOPLOT(14.0,17.0)
C     STEP 2 PROVIDE MAILING INSTRUCTIONS
      CALL SYMBL4(0.,2.0,0.17,94HMAIL TO D. W. HENDRICKS, UWRL, UTAH
     DSTATE UNIV., LOGAN, UTAH 84321  SEND BY FIRST CLASS MAIL,90.0,94)
C     STEP 3  ESTABLISH PERMANENT ORGIN FOR GRAPH.  THIS IS DONE BY (-1
      CALL PLOT(1.5,2.0,-3)
C     STEP 4  ESTABLISH X-AXIS, THEN Y-AXIS -LABEL EACH AXIS
      XP = NRUNS + 1
      CSQUM(XP) = 0.
      XSORT(XP) = 0.
      ALX = 10.0
      ALY = 8.0
      CALL SCALE (CSQUM,XP,   ALX,CMIN,DSTAR,1)
      CALL AXIS (0.0,0.0,15HCSTAR (MG/G/ML),-15,ALX,0.0,CMIN,DSTAR)
      CALL SCALE (XSORT,XP,   ALY,XMIN,DXXX,1)
      CALL AXIS (0.0,0.0,13HXBARSBSTAR (MG/G/ML),18,ALY,90.0,XBMIN,DXXX)
C     STEP 5 SHOW THE EXPERIMENTAL POINTS
      CALL PLOT(0.,+0.,3)
      DO 9 I = 1,NRUNS
```

Figure 27. Program listing of ALPHAB.

Figure 25 Continued. Listing of equilibrium data (see Figure 25).

Figure 28A. Output from ALPHAB - tabuler printout.

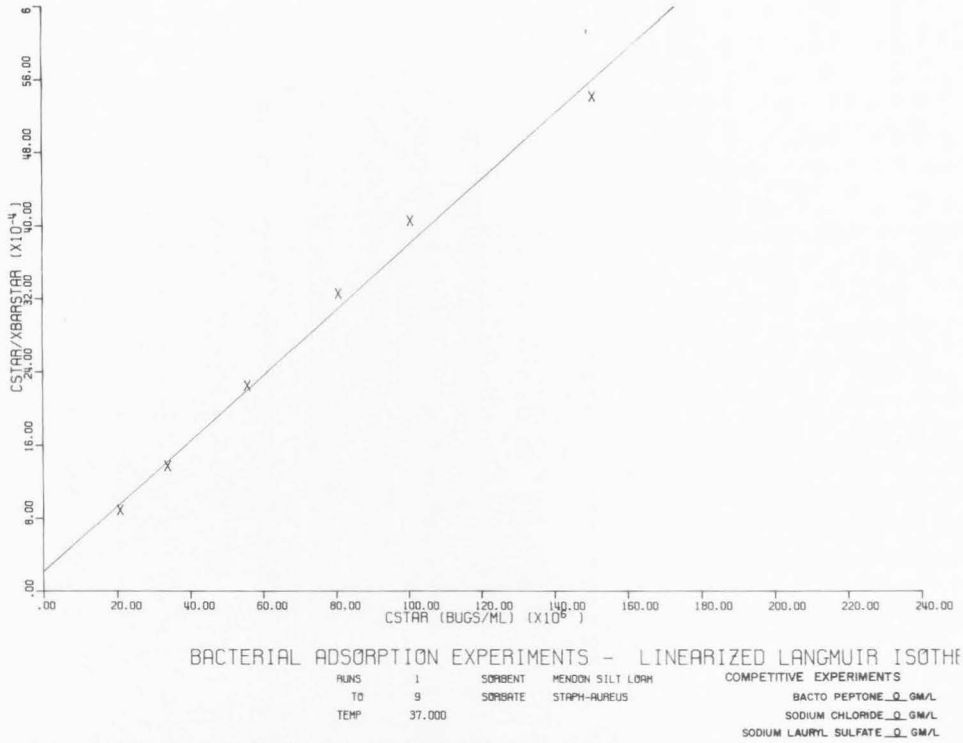


Figure 28B. Output from ALPHAB - Linearized Langmuir isotherm.

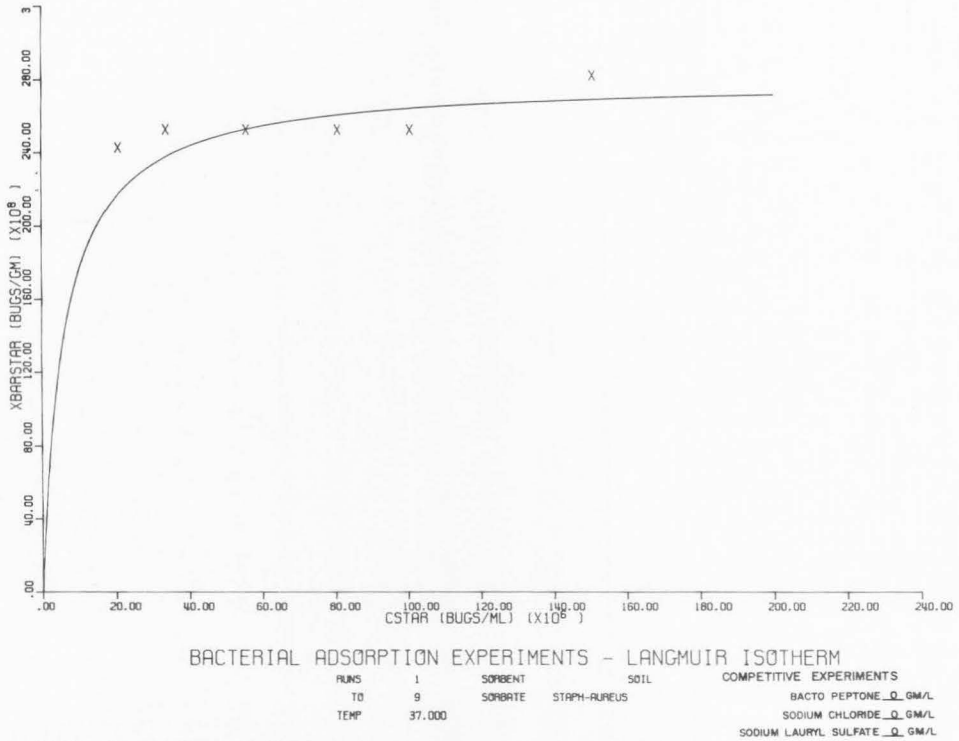


Figure 28C. Output from ALPHAB - Conventional Langmuir isotherm.

Appendix C

Toxicity of Sodium Lauryl Sulfate

The results of toxicity tests and control are presented in this appendix. Note that the control and the run with the SLS concentration of .05 gram per liter do not show cell depletion with time, but the run with .5 gram per liter of SLS does show the cell depletion, indicating its toxicity to S. aureus.

TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 10/29/69
HOUR 1500 HRS
RUN 6
TYPE OF RUN CONTROL

SORBATE STAPH-AUREUS FDA-209

SOL. VOL. 2000.0 ML

INITIAL CONC (SPECT READ) 20000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	1.	1.0	215. 0.	1.	215.	100.	21500.	0.
5.0	1.	1.0	200. 0.	1.	200.	100.	20000.	0.
15.0	1.	1.0	220. 0.	1.	220.	100.	22000.	0.
30.0	1.	1.0	215. 0.	1.	215.	100.	21500.	0.
45.0	1.	1.0	230. 0.	1.	230.	100.	23000.	0.
60.0	1.	1.0	210. 0.	1.	210.	100.	21000.	0.

BACTERIAL ADSORPTION

RUN 6
DATE 10/29/69 SORBATE STAPH-AUREUS
TEMP 27.000 STRAIN FDA-209
TYPE OF RUN CONTROL

TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 09/22/69
HOUR 1500 HRS
RUN 5
TYPE OF RUN TOXICITY

SORBATE STAPH-AUREUS
FDA-209
LAURYL-SULFATE
0.05GM/L

SOL. VOL. 2000.0 ML

INITIAL CONC (SPECT READ) 20000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	1.	1.0	225. 0.	1.	225.	100.	20250.	0.
5.0	1.	1.0	230. 0.	1.	230.	100.	23000.	0.
15.0	1.	1.0	215. 0.	1.	215.	100.	21500.	0.
30.0	1.	1.0	225. 0.	1.	225.	100.	22500.	0.
45.0	1.	1.0	220. 0.	1.	220.	100.	22000.	0.
60.0	1.	1.0	195. 0.	1.	195.	100.	19500.	0.

BACTERIAL ADSORPTION

RUN 5
DATE 09/22/69
TEMP 27.000
TYPE OF RUN

LAURYL SULFATE
SORBATE STAPH-AUREUS
STRAIN FDA-209
TOXICITY, .05 GM/L LAURYL SULFATE

TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 09/22/69
HOUR 1500 HRS
RUN 3
TYPE OF RUN TOXICITY

SORBATE STAPH-SUREUS
EDA-220
LAURYL-SULFATE
0.500M/L

SOL. VOL. 2000.0 ML

INITIAL CONC (SPECT READ) 20000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/CM)
.0	1.	1.0	275. 0.	1.	275.	100.	24750.	0.
5.0	1.	1.0	165. 0.	1.	165.	100.	16500.	0.
15.0	1.	1.0	70. 0.	1.	70.	100.	7000.	0.
30.0	1.	1.0	0. 0.	1.	0.	100.	0.	0.
45.0	1.	1.0	6. 0.	1.	6.	100.	600.	0.
60.0	1.	1.0	2. 0.	1.	2.	100.	200.	0.

BACTERIAL ADSORPTION

RUN 8 LAURYL-SULFATE
DATE 09/22/69 SORBATE STAPH-SUREUS
TEMP 27.000 STRAIN FDA-209
TYPE OF RUN TOXICITY, 0.50 GM/L LAURYL SULFATE

Appendix D

Toxicity of Peptone

This appendix includes peptone toxicity runs. Peptone concentrations of 10 grams and 30 grams per liter do not show toxic effect on S. aureus.

TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 09/23/69
HOUR 1500 HRS
RUN 12
TYPE OF RUN TOXICITY

SORBATE STAPH-AUREUS FDA-209
PEPTONE
10.00GM/L
SOL. VOL. 2000.0 ML
INITIAL CONC (SPECT READ) 20000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	1.	1.0	640. 0.	1.	640.	100.	57600.	0.
5.0	1.	1.0	710. 0.	1.	710.	100.	71000.	0.
15.0	1.	1.0	535. 0.	1.	535.	100.	53500.	0.
30.0	1.	1.0	585. 0.	1.	585.	100.	58500.	0.
45.0	1.	1.0	580. 0.	1.	580.	100.	58000.	0.
60.0	1.	1.0	610. 0.	1.	610.	100.	61000.	0.

BACTERIAL ADSORPTION

RUN	12		PEPTONE
DATE	09/23/69	SORBATE	STAPH-AUREUS
TEMP	27.000	STRAIN	FDA-209
TYPE OF RUN		TOXICITY, 9.0 GM/L PEPTONE	

TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 09/23/69
HOUR 1500 HRS
RUN 13
TYPE OF RUN TOXICITY

SORBATE STAPH-AUREUS FDA-209
PEPTONE
30.000GM/L
SOL. VOL. 2000.0 ML
INITIAL CONC (SPECT READ) 20000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	1.	1.0	910. 0.	1.	455.	100.	45500.	0.
5.0	1.	1.0	445. 0.	1.	445.	100.	44500.	0.
15.0	1.	1.0	535. 0.	1.	535.	100.	53500.	0.
30.0	1.	1.0	510. 0.	1.	510.	100.	51000.	0.
45.0	1.	1.0	580. 0.	1.	580.	100.	58000.	0.
60.0	1.	1.0	460. 0.	1.	460.	100.	46000.	0.

BACTERIAL ADSORPTION
XBAR (BACTERIA/GM SORBENT)
SOLUTION CONCENTRATION (BACTERIA/ML) (X10²)
TIME (MIN)
RUN 13
DATE 09/23/69
TEMP 27.000
SORBATE STAPH-AUREUS
STRAIN FDA-209
PEPTONE
TYPE OF RUN TOXICITY, 30.0 GM/L PEPTONE

Appendix E

Toxicity of Sodium Chloride (NaCl)

Sodium chloride concentrations of 150 grams and 200 grams per liter show a toxic effect on S. aureus. However, 40 grams per liter of NaCl did not exhibit toxicity. These toxicity runs are presented in this appendix.

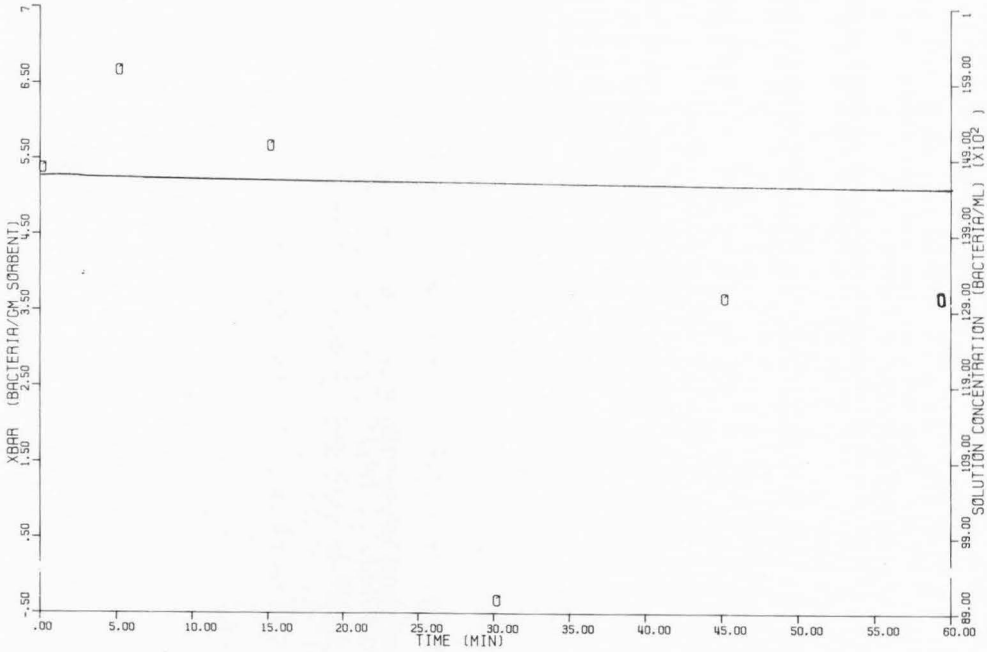
TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 09/25/69
HOUR 1500 HRS
RUN 17
TYPE OF RUN TOXICITY

SORBATE STAPH-AUREUS FDA-209
SORBENT SODIUM CHLORIDE 40.00GM/L
INITIAL CONC (SPECT READ) 20000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

SOL. VOL. 2000.0 ML
SORBENT WT. (OD)100.0 GM

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML FB.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	1.	1.0	210. 0.	1.	210.	100.	14700.	0.
5.0	1.	1.0	160. 0.	1.	160.	100.	16000.	0.
15.0	1.	1.0	150. 0.	1.	150.	100.	15000.	0.
30.0	1.	1.0	90. 0.	1.	90.	100.	9000.	0.
45.0	1.	1.0	130. 0.	1.	130.	100.	13000.	0.
60.0	1.	1.0	130. 0.	1.	130.	100.	13000.	0.



BACTERIAL ADSORPTION

RUN	17	SORBENT	SODIUM CHLORIDE
DATE	09/25/69	SORBATE	STAPH-AUREUS
TEMP	27.000	STRAIN	FDA-209
TYPE OF RUN		TOXICITY	40.0 GM/L NACL

TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 12/17/69
HOUR 1500 HRS
RUN 23
TYPE OF RUN TOXICITY

SORBATE STAPH-AUREUS FDA-209
200.0 GM/L NACL

SOL. VOL. 1700.0 ML

INITIAL CONC (SPECT READ) 80000000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	3.	1.0	75. 0.	1.	75.	1000000.	74999999.	0.
5.0	3.	1.0	60. 0.	1.	60.	1000000.	60000000.	0.
15.0	3.	1.0	40. 0.	1.	40.	1000000.	40000000.	0.
30.0	3.	1.0	35. 0.	1.	35.	1000000.	35000000.	0.
45.0	3.	1.0	45. 0.	1.	45.	1000000.	45000000.	0.
60.0	3.	1.0	35. 0.	1.	35.	1000000.	35000000.	0.

BACTERIAL ADSORPTION
RUN 23
DATE 12/17/69
TEMP 27.000
TYPE OF RUN
SORBATE STAPH-AUREUS
STRAIN FDA-209
TOXICITY, 200.0 GM/L NACL
NACL
XBAR (BACTERIA/CM SORBENT)
TIME (MIN)
SOLUTION CONCENTRATION (BACTERIA/ML) (X10^3)

TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

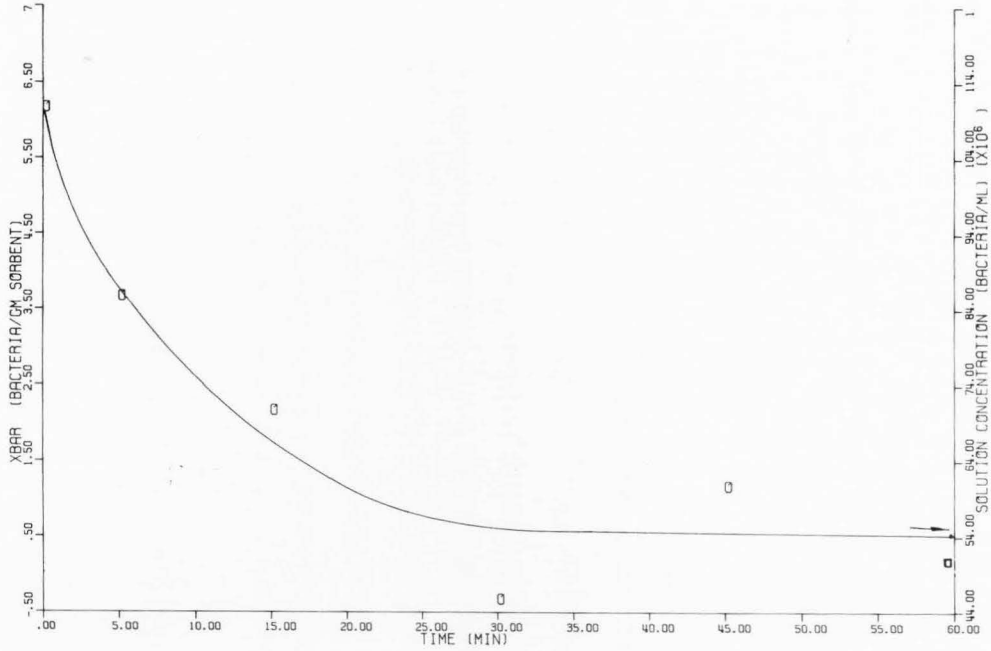
DATE 03/02/70
HOUR 15.00 HRS
RUN 25
TYPE OF RUN TOXICITY

SORBATE STAPH-AUREUS FDA-209
150.0 GM/L NACL

SOL. VOL. 200.0 ML

INITIAL CONC (SPECT READ) 100000000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	3.	1.0	110. 0.	1.	110.	1000000.	110000000.	0.
5.0	3.	1.0	85. 0.	1.	85.	1000000.	85000000.	0.
15.0	3.	1.0	70. 0.	1.	70.	1000000.	70000000.	0.
30.0	3.	1.0	45. 0.	1.	45.	1000000.	45000000.	0.
45.0	3.	1.0	60. 0.	1.	60.	1000000.	60000000.	0.
60.0	3.	1.0	50. 0.	1.	50.	1000000.	50000000.	0.



BACTERIAL ADSORPTION

RUN	25		NACL
DATE	03/02/70	SORBATE	STAPH-AUREUS
TEMP	27.000	STRAIN	FDA-209
TYPE OF RUN		TOXICITY, 150.0 GM/L NACL	

Appendix F

Competitive Effect of Sodium Lauryl Sulfate

This appendix includes the bacterial adsorption runs with and without SLS (.05 gram per liter). SLS concentration, .05 gram per liter, does not show significant competition with bacteria for adsorption at 27 C. The SLS concentrations greater than .05 gram per liter were above the threshold toxic level (Figure 8). Therefore, to determine the bacterial adsorption isotherms at other experimental temperatures (i.e. 10C, 20C, and 37C) SLS concentration of .05 gram per liter was selected.

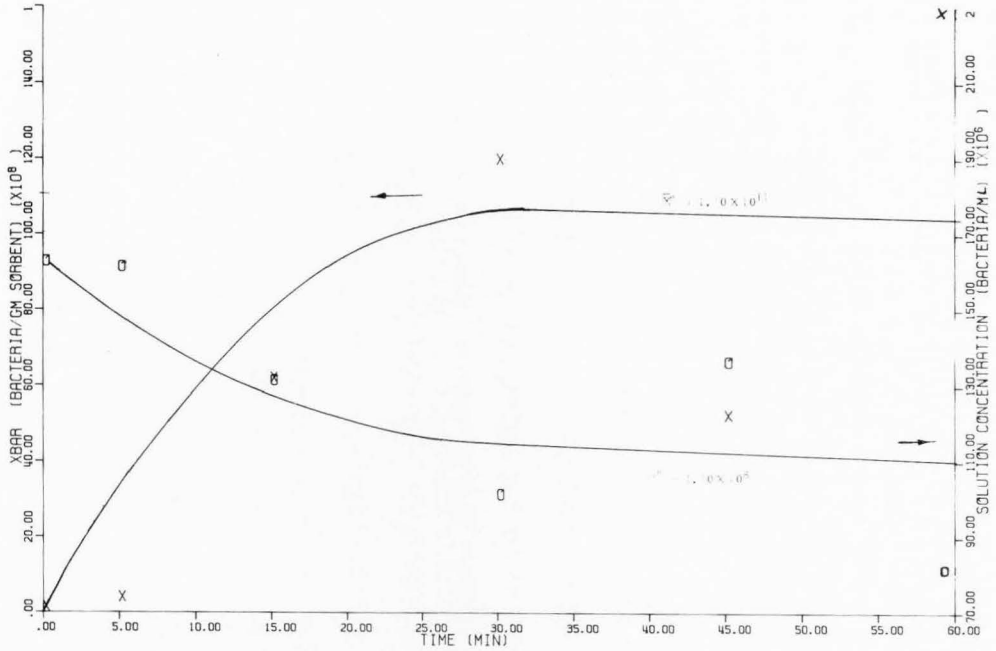
TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 10/24/69
HOUR 1500 HRS
RUN 1
TYPE OF RUN 0.005E/L

SORBATE STAPH-AUREUS FDA-209
SORBENT SOIL
MENDON SILT LOAM
INITIAL CONC (SPECT READ) 200000000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

SOL. VOL. 1935.0 ML
SORBENT WT. (OD) 10.0 GM

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	3.	1.0	180. 0.	1.	180.	1000000.	161395348.	0.
5.0	3.	1.0	160. 0.	1.	160.	1000000.	160000000.	267999718.
15.0	3.	1.0	130. 0.	1.	130.	1000000.	130000000.	606999680.
30.0	3.	1.0	100. 0.	1.	100.	1000000.	100000000.	1186299808.
45.0	3.	1.0	135. 0.	1.	135.	1000000.	135000000.	510449840.
60.0	3.	1.0	80. 0.	1.	80.	1000000.	80000000.	1571949976.



BACTERIAL ADSORPTION

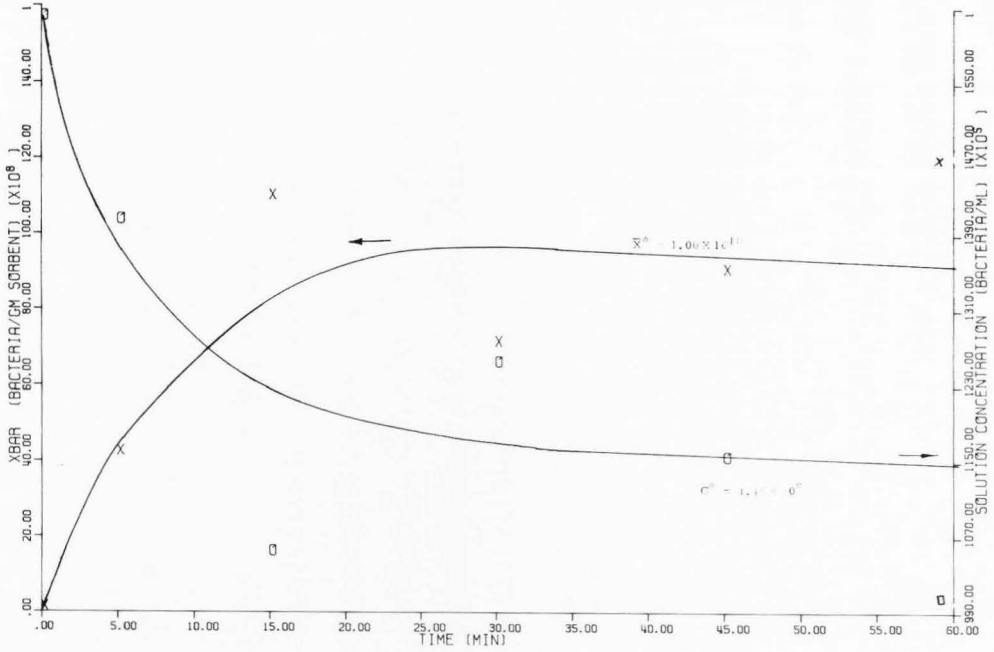
RUN	1	SORBENT	MENDON SILT LOAM
DATE	10/24/69	SORBATE	STAPH-AUREUS
TEMP	27.000	STRAIN	FDA-209
TYPE OF RUN		COMPETITIVE, 0.0 GM/L LAURYL SULFATE	

TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 10/24/69
HOUR 1500 HRS
RUN 2
TYPE OF RUN .05LSB/L

SORBATE STAPH-AUREUS FDA-209
SOLN. VOL. 1935.0 ML
SORBENT WT. (GM) 10.0 GM
SORBENT SOIL
MENDON SILT LOAM
INITIAL CONC (SPECT READ) 200000000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	3.	1.0	180. 0.	1.	180.	1000000.	161395348.	0.
5.0	3.	1.0	140. 0.	1.	140.	1000000.	140000000.	41359398872.
15.0	3.	1.0	105. 0.	1.	105.	1000000.	105000000.	10901499520.
30.0	3.	1.0	125. 0.	1.	125.	1000000.	125000000.	7037499648.
45.0	3.	1.0	115. 0.	1.	115.	1000000.	115000000.	8968499712.
60.0	3.	1.0	100. 0.	1.	100.	1000000.	100000000.	11863499776.



BACTERIAL ADSORPTION

RUN	2	SORBENT	MENDON SILT LOAM
DATE	10/24/69	SORBATE	STAPH-AUREUS
TEMP	27.000	STRAIN	FDA-209
TYPE OF RUN		COMPETITIVE, .05 GM/L LAURYL SULFATE	

Appendix G

Competitive Effect of Peptone

The lower peptone concentration (3.5 grams per liter) permits bacterial uptake, but the higher peptone concentration (30 grams per liter) inhibits bacterial uptake. These results are included in this appendix.

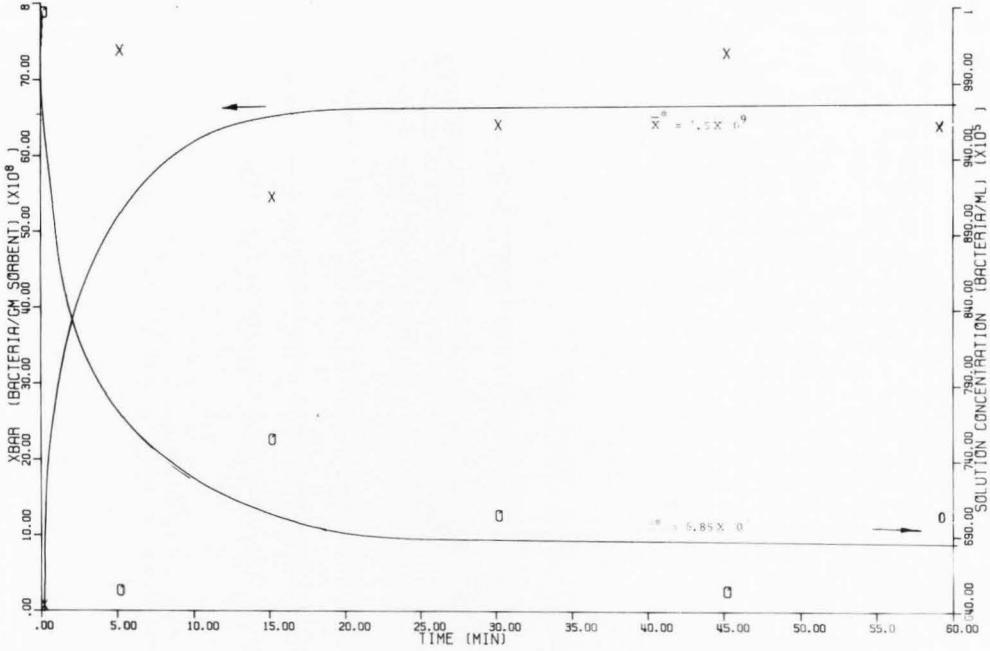
TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 11/10/69
HOUR 1500 HRS
RUN 7
TYPE OF RUN 0.05PER/L

SORBATE STAPH-AUREUS FDA-209
SORBENT SOIL
MENDON SILT LOAM
INITIAL CONC (SPECT READ) 100000000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

SOL. VOL. 1925.0 ML
SORBENT WT. (OD) 10.0 GM

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	3.	1.0	115. 0.	1.	115.	1000000.	103051947.	0.
5.0	3.	1.0	65. 0.	1.	65.	1000000.	65000000.	7319999744.
15.0	3.	1.0	75. 0.	1.	75.	1000000.	75000000.	5396999680.
30.0	3.	1.0	70. 0.	1.	70.	1000000.	70000000.	6357999744.
45.0	3.	1.0	65. 0.	1.	65.	1000000.	65000000.	7318499584.
60.0	3.	1.0	70. 0.	1.	70.	1000000.	70000000.	6358499648.



BACTERIAL ADSORPTION

RUN	7	SORBENT	MENDON SILT LOAM
DATE	11/10/69	SORBATE	STAPH-AUREUS
TEMP	27.000	STRAIN	FDA 209
TYPE OF RUN	COMPETITIVE,0.0 GM/L PEPTONE		

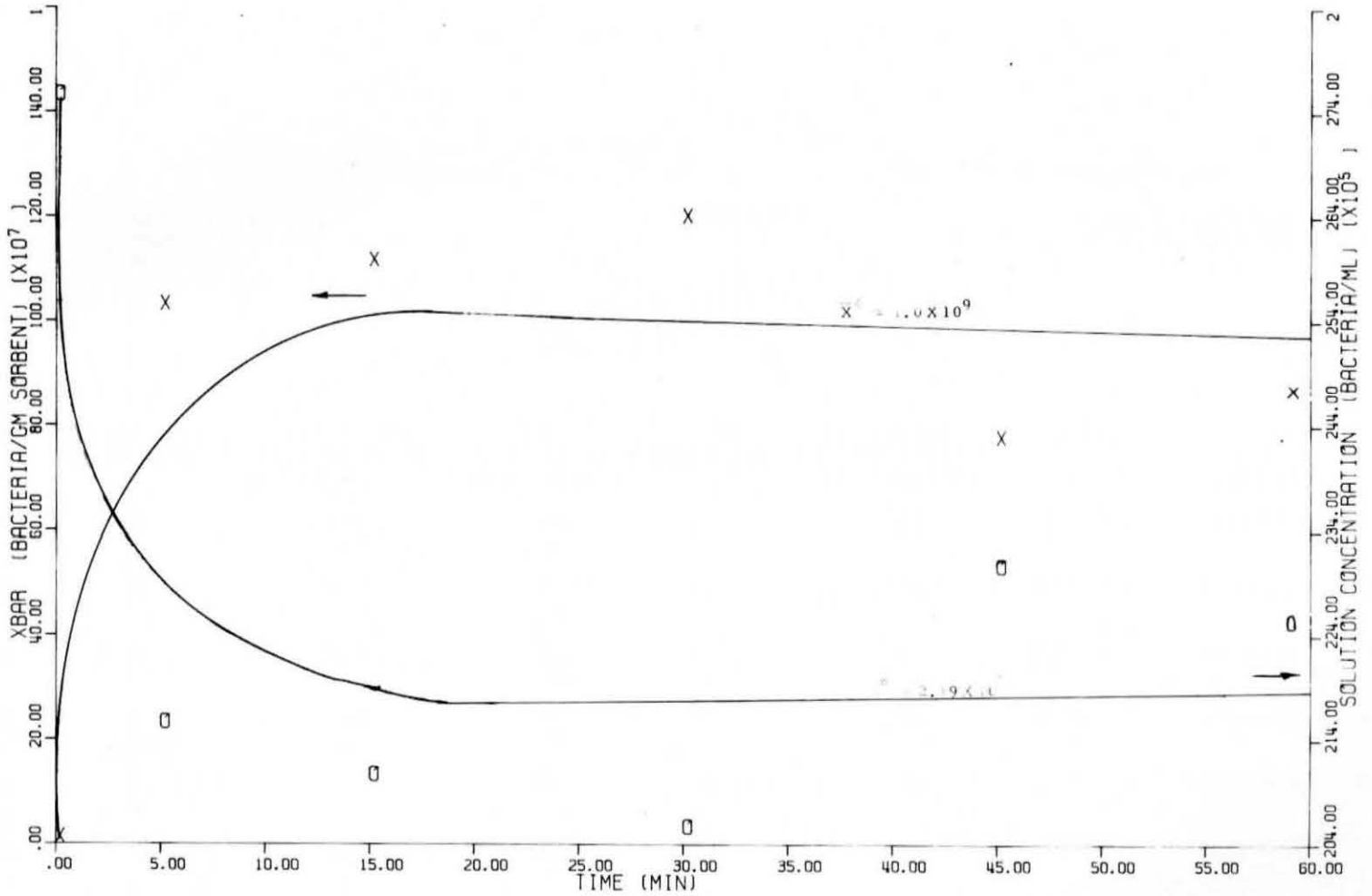
TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 11/25/69
HOUR 1500 HRS
RUN 30
TYPE OF RUN 3.5SPP/L

SORBATE STAPH-AUREUS FDA-209
SORBENT SOIL
MENDON SILT LOAM
INITIAL CONC (SPECT READ) 30000000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

SOL. VOL. 1700.0 ML
SORBENT WT. (OD) 15.0 GM

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	2.	.1	275. 0.	1.	275.	100000.	27500000.	0.
5.0	2.	.1	215. 0.	1.	215.	100000.	21500000.	1019399936.
15.0	2.	.1	210. 0.	1.	210.	100000.	21000000.	1104299936.
30.0	2.	.1	205. 0.	1.	205.	100000.	20500000.	1188149504.
45.0	2.	.1	230. 0.	1.	230.	100000.	23000000.	765149920.
60.0	2.	.1	225. 0.	1.	225.	100000.	22500000.	849899968.



BACTERIAL ADSORPTION

RUN	30	SORBENT	MENDON SILT LOAM
DATE	11/25/69	SORBATE	STAPH-AUREUS
TEMP	27.000	STRAIN	FDA-209
TYPE OF RUN		COMPETITIVE, 3.5 GM/L PEPTONE	

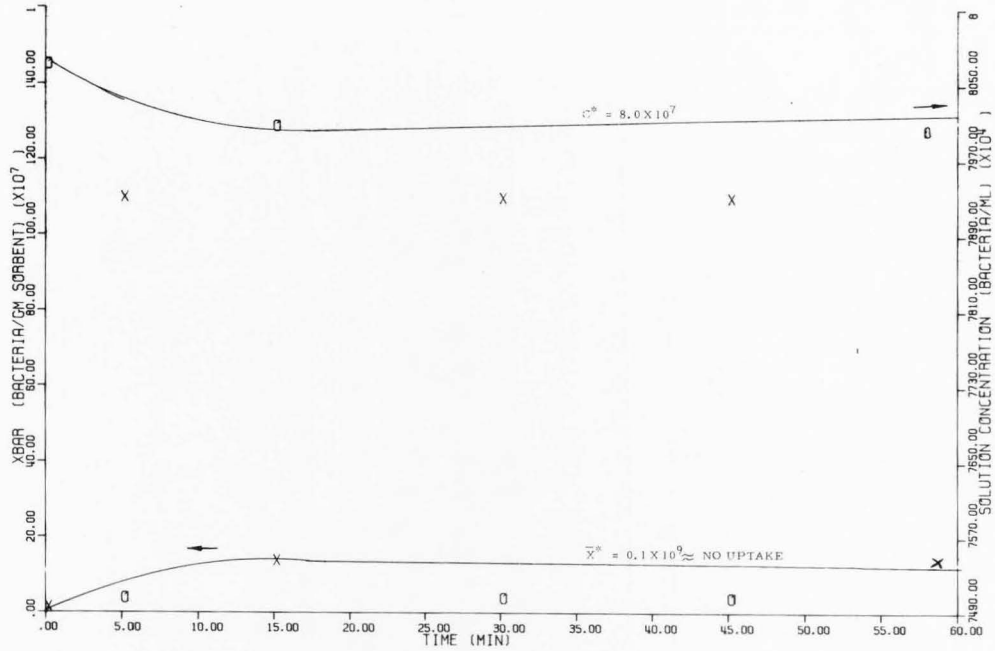
TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 11/10/69
HOUR 1500 HRS
RUN 11
TYPE OF RUN 30GPER/L

SORBATE STAPH-AUREUS FDA-209
SORBENT SOIL
MENDON SILT LOAM
INITIAL CONC (SPECT READ) 100000000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

SOL. VOL. 1925.0 ML
SORBENT WT. (OD) 10.0 GM

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	3.	1.0	93. 0.	1.	93.	1000000.	80649350.	0.
5.0	3.	1.0	75. 0.	1.	75.	1000000.	75000000.	1085999840.
15.0	3.	1.0	80. 0.	1.	80.	1000000.	80000000.	124499782.
30.0	3.	1.0	75. 0.	1.	75.	1000000.	75000000.	1085499792.
45.0	3.	1.0	75. 0.	1.	75.	1000000.	75000000.	1085499776
60.0	3.	1.0	80. 0.	1.	80.	1000000.	80000000.	125499884



BACTERIAL ADSORPTION

RUN	11	SORBENT	MENDON SILT LOAM
DATE	11/10/69	SORBATE	STAPH-AUREUS
TEMP	27.000	STRAIN	FDA-209
TYPE OF RUN		COMPETITIVE, 30.0 GM/L PEPTONE	

Appendix H

Competitive Effect of NaCl

The runs on bacterial adsorption with and without NaCl are presented in this appendix. The bacterial uptake did occur at both NaCl concentrations tried (30 grams and 100 grams per liter) at 27C. Since NaCl concentrations greater than 30 grams per liter were beyond the practical experimental limits, the NaCl concentration (30 grams per liter) was chosen to determine the bacterial adsorption isotherms at other experimental temperatures (i.e. 10C, 20C, and 37C).

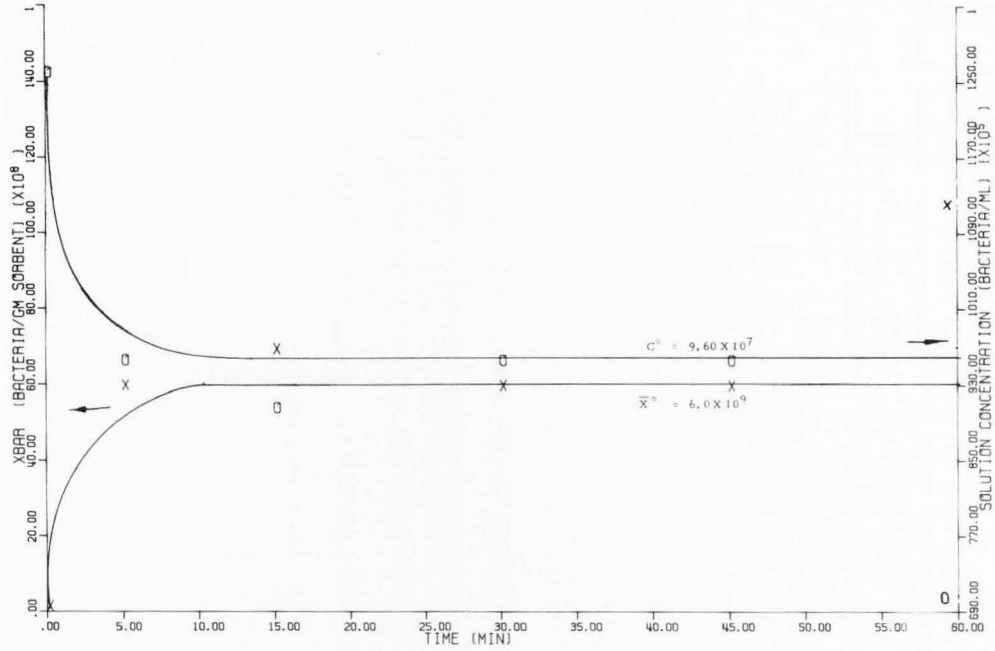
TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 10/29/69
HOUR 1500 HRS
RUN 3
TYPE OF RUN 30.0 GM/L NACL

SORBATE STAPH-AUREUS FDA-209
SORBENT SOIL MENDON SILT LOAM
INITIAL CONC (SPECT READ) 1250[illegible]. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

SOL. VOL. 1963.0 ML
SORBENT WT. (GM) 10.0 GM

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	3.	1.0	140. 0.	1.	140.	1[illegible].	12561[illegible].	0.
5.0	3.	1.0	95. 0.	1.	95.	1[illegible].	[illegible].	5835499904.
15.0	3.	1.0	90. 0.	1.	90.	1[illegible].	[illegible].	6734499840.
30.0	3.	1.0	95. 0.	1.	95.	1[illegible].	[illegible].	5835999808.
45.0	3.	1.0	95. 0.	1.	95.	1[illegible].	[illegible].	5835999872.
60.0	3.	1.0	70. 0.	1.	70.	1[illegible].	7[illegible].	1[illegible].



BACTERIAL ADSORPTION

RUN	8	SORBENT	MENDON SILT LOAM
DATE	10/29/69	SORBATE	STAPH-AUREUS
TEMP	27.000	STRAIN	FDA-209
TYPE OF RUN		COMPETITIVE, 30.0GM/L NACL	

TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 01/30/70
HOUR 1500 HRS
RUN 24
TYPE OF RUN 100.0 GM/L NACL

SORBATE STAPH-AUREUS FDA-209
SORBENT SOIL MENDON SILT LOAM
INITIAL CONC (SPECT READ) 75000000. BUGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

SOL. VOL. 200.0 ML
SORBENT WT. (OD) 1.0 GM

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. DEL. TO PLATE (ML)	FILTER PLATE COUNT (BUGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (BUGS/PLATE)	DIL. FACT.	SOLUTION CONC. (BUGS/ML)	XBAR (BUGS/GM)
.0	3.	1.0	80. 0.	1.	80.	1000000.	68000000.	0.
5.0	3.	1.0	15. 0.	1.	15.	1000000.	15000000.	105350000 64.
15.0	3.	1.0	30. 0.	1.	30.	1000000.	30000000.	756500000 00.
30.0	3.	1.0	15. 0.	1.	15.	1000000.	15000000.	1052000000 00.
45.0	3.	1.0	20. 0.	1.	20.	1000000.	20000000.	954000000 00.
60.0	3.	1.0	15. 0.	1.	15.	1000000.	15000000.	105150000 64.

BACTERIAL ADSORPTION

RUN	24	SORBENT	MENDON SILT LOAM
DATE	01/30/70	SORBATE	STAPH-AUREUS
TEMP	27.000	STRAIN	FDA-209
TYPE OF RUN		COMPETITIVE, 100.0 GM/L NACL	

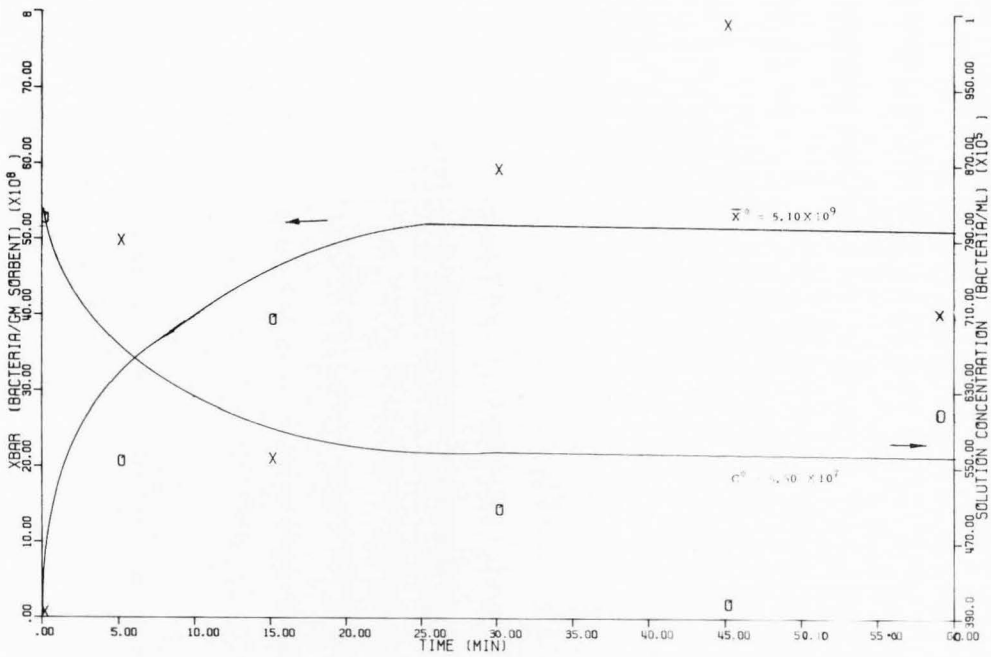
TABLE 2 BACTERIAL ADSORPTION EXPERIMENTS - COLLECTION AND REDUCTION OF DATA

DATE 12/16/69
HOUR 1500 HRS
RUN 13
TYPE OF RUN 0.0 GM/L NACL

SORBATE STAPH-AUREUS FDA-209
SORBENT SOIL
MENDON SILT LOAM
INITIAL CONC (SPECT READ) [illegible] ORGS/ML
TEMP 27.0 DEG. C.
SAMPLE VOL. 1.0 ML

SOL. VOL. [illegible] ML
SORBENT WT. (DRY) 10.0 GM

ELAPSED TIME (MIN)	NO. OF DIL. OF 99 ML EA.	PIPET VOL. (ML) TO PLATE	FILTER PLATE COUNT (ORGS/PLATE)	NO. OF VALID OBS.	AVG FILTER PLATE COUNT (ORGS/PLATE)	DIL. FACT.	SOLUTION CONC. (ORGS/ML)	XBAR (ORGS/GM)
.0	3.	1.0	90. 0.	1.	90.	[illegible]	[illegible]	0.
5.0	3.	1.0	85. 0.	1.	85.	[illegible]	[illegible]	4916499712.
15.0	3.	1.0	70. 0.	1.	70.	[illegible]	[illegible]	2033499904.
30.0	3.	1.0	50. 0.	1.	50.	[illegible]	[illegible]	1373499840.
45.0	3.	1.0	40. 0.	1.	40.	[illegible]	[illegible]	775999904.
60.0	3.	1.0	60. 0.	1.	60.	[illegible]	[illegible]	1353499072.



BACTERIAL ADSORPTION

RUN	13	SORBENT	MENDON SILT LOAM
DATE	10/16/69	SORBAT	STAPH-AUREUS
TEMP	27.00	STRAIN	FDA-209
TYPE OF RUN		COMPETITIVE, 0.0 GM/L NACL	

Appendix I

Bacterial Adsorption Isotherms (Without Chemical Competition)

Bacto-Peptone 0 GM/L

Sodium Chloride 0 GM/L

Sodium Lauryl Sulfate 0 GM/L

Bacterial adsorption isotherms (Langmuir and linear) in the absence of chemical competition are shown in this appendix. These isotherms were obtained at 10C, 20C, 27C, and 37C. The output in the tables shows the isotherm parameters such as α (the equilibrium constant), X_{max} (the maximum adsorption capacity of adsorbent), and R^2 (the regression coefficient). These results are summarized in the text, in Table 1, p.63 .

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 10/15/69
RUNS 5 TO 18

SORBATE STAPH-AUREUS FDA-209
SORBENT MENDON SILT LOAM MENDON
TEMP 10.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

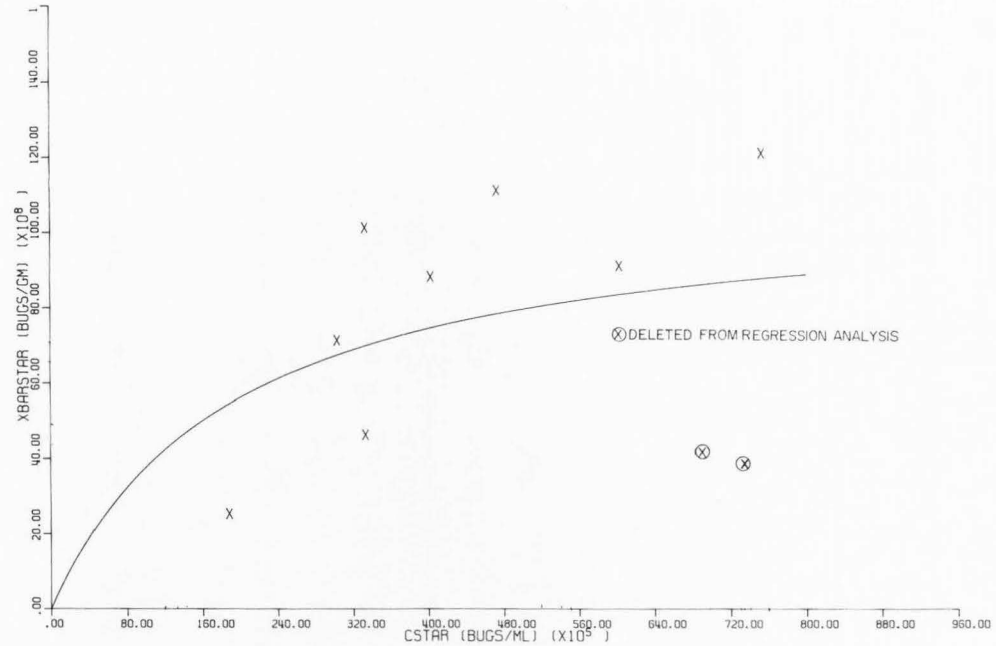
R = .838
RSQ = .701
YINTERCEPT = 1/(ALPHA*XMAX) = .175168-02
SLOPE OF BEST FIT = .907448-10
ALPHA = .515761-07
XMAX = .110597+11

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

	RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
	5	10/15/69	.47000+08	.11000+11	.42727-02
	6	10/15/69	.33000+08	.10000+11	.33000-02
	8	10/17/69	.75000+08	.12000+11	.62500-02
	9	10/17/69	.33000+08	.45000+10	.73333-02
	10	10/17/69	.40000+08	.87000+10	.45977-02
	11	10/17/69	.30000+08	.70000+10	.42857-02
	12	10/17/69	.18500+08	.24000+10	.77083-02
	18	10/23/69	.60000+08	.90000+10	.66667-02
⊗	16	10/23/69	.73000+08	.40000+10	.18250-01
⊗	17	10/23/69	.70000+08	.45000+10	.15556-01
Δ	2	10/15/69	.70000+08	.23000+11	.30435-02
Δ	3	10/15/69	.66000+08	.17000+11	.38824-02
Δ	4	10/15/69	.55000+08	.15800+11	.34810-02
Δ	14	10/23/69	.13300+09	.45000+10	.29556-01
Δ	15	10/23/69	.12000+09	.65000+10	.18462-01

⊗ Deleted from regression analysis but plotted on Figures

Δ Off the scale, therefore not shown in Figures



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

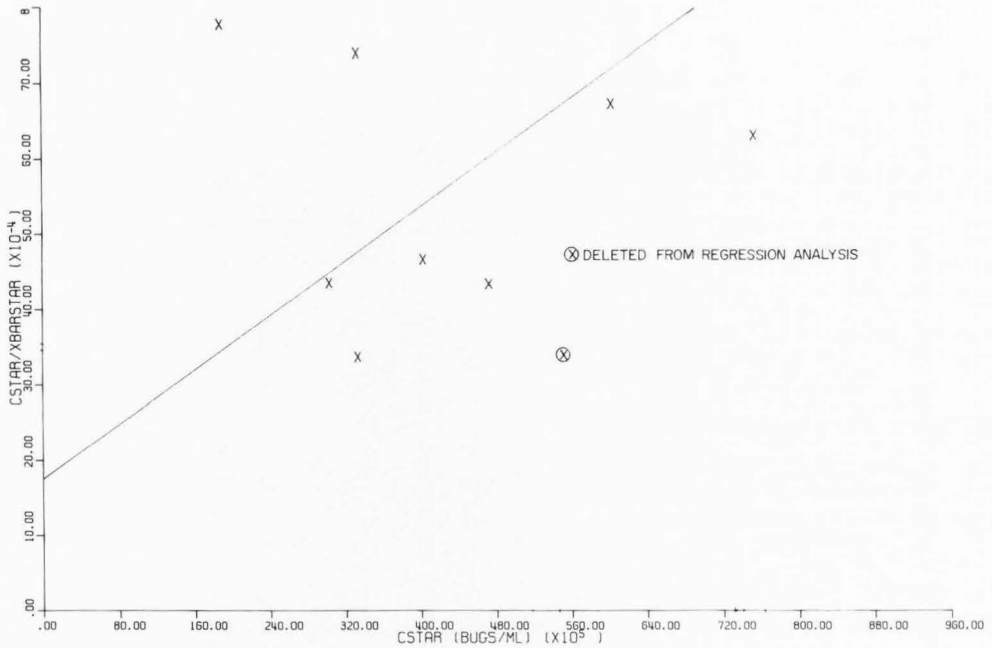
RUNS	5	SORBENT	MENDON SILT LOAM
TO	18	SORBATE	STAPH- JREUS
TEMP	10.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	5	SORBENT	MENDON SILT LOAM
TO	18	SORBATE	STAPH-AUREUS
TEMP	10.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 01022070
RUNS 3 TO 15

SORBATE STAPH-AUREUS FDA-209
SORBENT SOIL MENDON SILT LOAM
TEMP 20.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

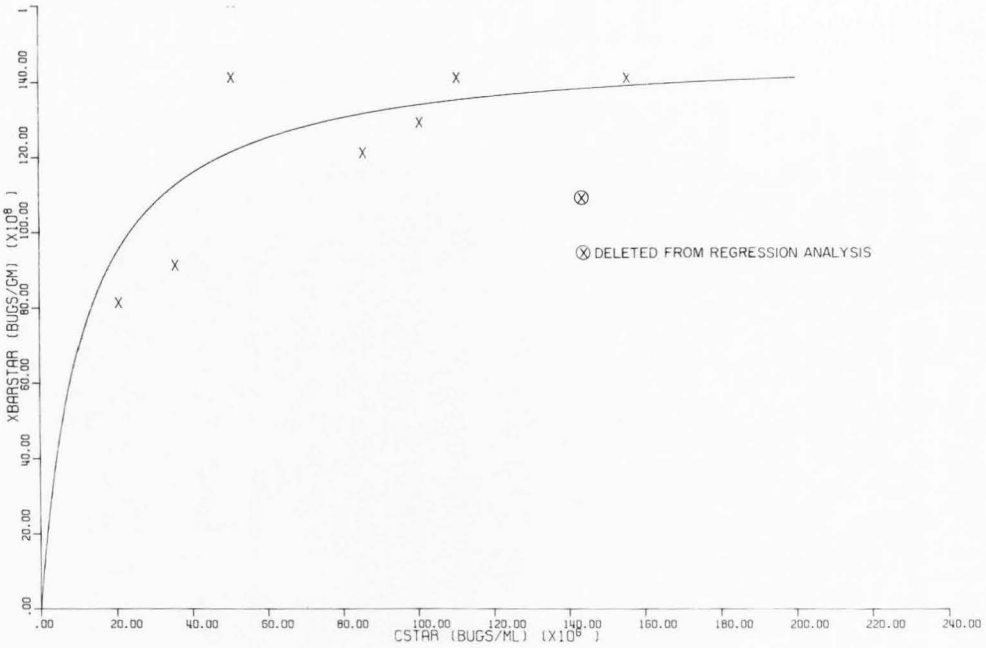
R = .980
RSQ = .961
YINTERCEPT = 1/(ALPHA*XMAX) = .788731-03
SLOPE OF BEST FIT = .666689-10
ALPHA = .845268-07
XMAX = .149995+11

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

	RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
	3	01022070	.50000+08	.16000+11	.31250-02
	4	01022070	.35000+08	.90000+10	.38889-02
	5	01022070	.20000+08	.80000+10	.25000-02
	7	01025070	.11000+09	.14000+11	.78571-02
	9	01025070	.50000+08	.14000+11	.35714-02
	11	01028070	.15500+09	.14000+11	.11071-01
	13	01028070	.11000+09	.14000+11	.78571-02
	14	01028070	.10000+09	.12800+11	.78125-02
	15	01028070	.85000+08	.12000+11	.70833-02
⊗	12	01002070	.14500+09	.11000+11	.13182-01
Δ	1	01002070	.70000+08	.20000+11	.35000-02
Δ	2	01002070	.58000+08	.17000+11	.34118-02
Δ	8	01002070	.78000+08	.16000+11	.48750-02

⊗ Deleted from regression analysis but plotted on Figures

Δ Off the scale, therefore not shown in Figures



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

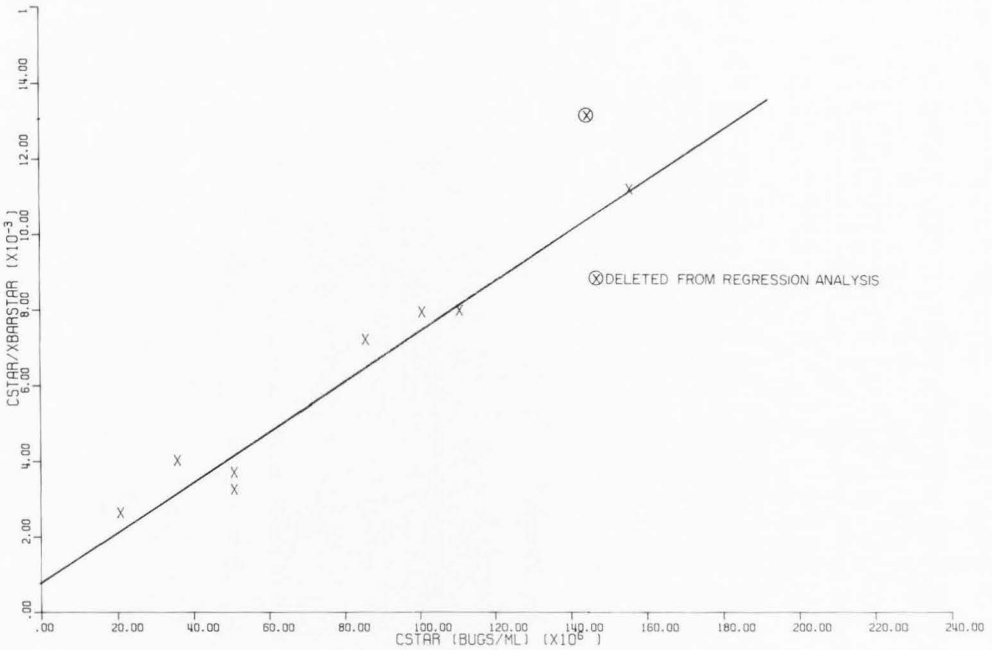
RUNS	3	SORBENT	MENDON SILT LOAM
TO	15	SORBATE	STAPH-AUREUS
TEMP	20.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	3	SORBENT	MENDON SILT LOAM
TO	15	SORBATE	STAPH-AUREUS
TEMP	20.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 10/01/69
RUNS 2 TO 18

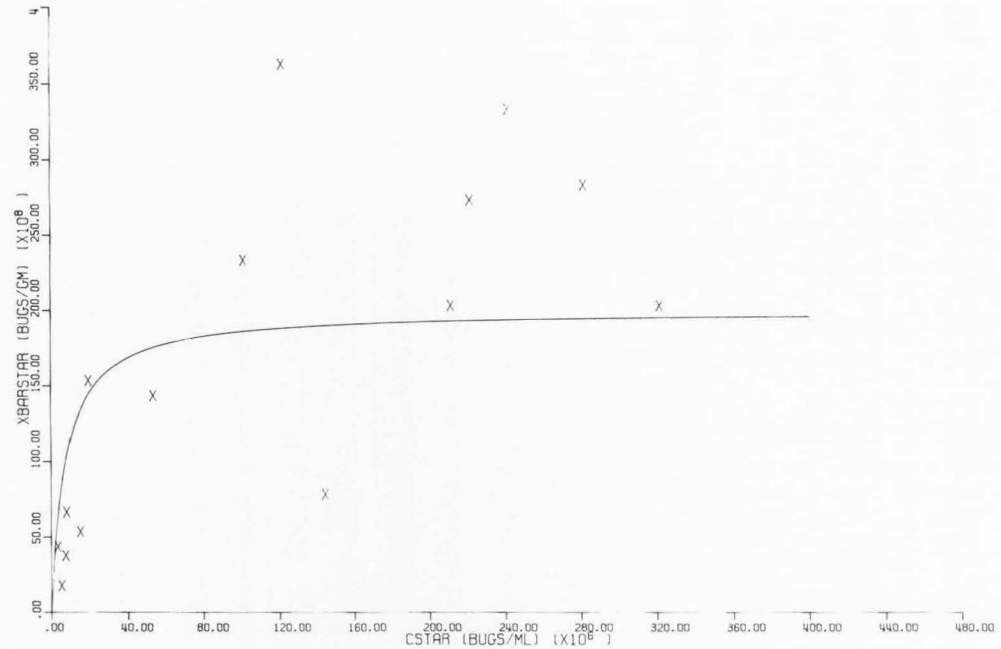
SORBATE STAPH-AUREUS FDA-209
SORBENT SOIL MENDON SILT LOAM
TEMP 27.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .766
RSQ = .587
YINTERCEPT = 1/(ALPHA*XMAX) = .373603-03
SLOPE OF BEST FIT = .499710-10
ALPHA = .133754-06
XMAX = .200116+11

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	(1/C**XBAR*)
2	10/01/69	.14300+09	.75000+10	.19067-01
3	10/01/69	.24000+09	.33000+11	.72727-02
4	10/01/69	.28000+09	.28000+11	.10000-01
5	10/03/69	.38000+07	.14000+10	.27143-02
6	10/03/69	.60000+07	.34000+10	.17647-02
7	10/03/69	.13500+08	.50000+10	.27000-02
8	10/03/69	.10000+09	.23000+11	.43478-02
10	10/07/69	.32000+09	.20000+11	.16000-01
11	10/07/69	.21000+09	.20000+11	.10500-01
12	10/07/69	.22000+09	.27000+11	.81481-02
13	10/07/69	.12000+09	.36000+11	.33333-02
15	10/09/69	.20000+07	.40000+10	.50000-03
16	10/09/69	.65000+07	.63000+10	.10317-02
17	10/09/69	.18000+08	.15000+11	.12000-02
18	10/09/69	.52000+08	.14000+11	.37143-02



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

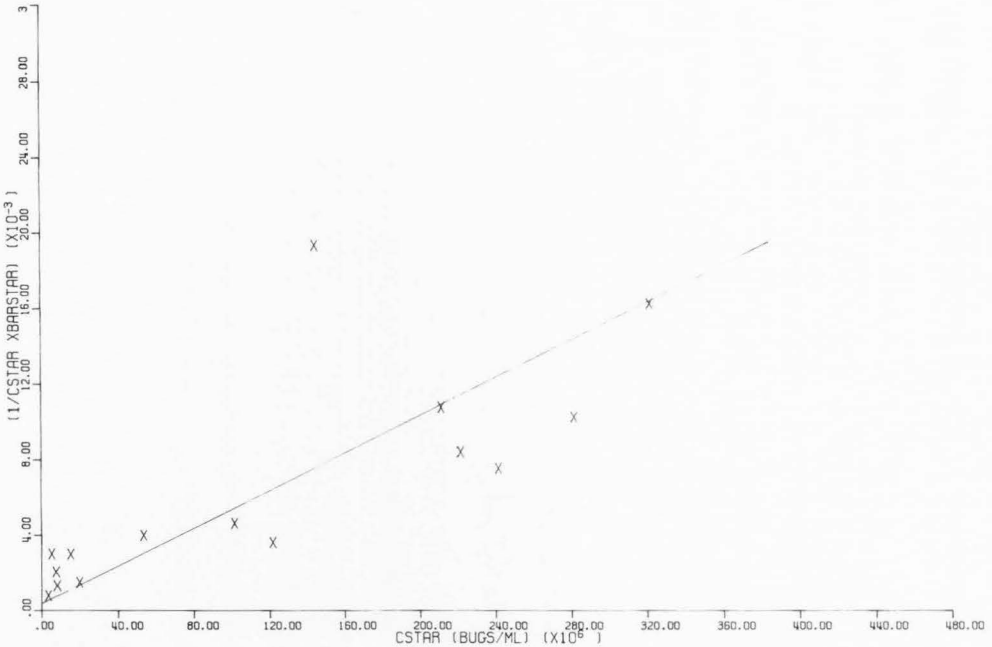
RUNS	2	SORBENT	MENDON SILT LOAM
TO	18	SORBATE	STAPH-AUREUS
TEMP	27.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	2	SORBENT	MENDON SILT LOAM
TC	18	SORBATE	STAPH-AUREUS
TEMP	27.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 01/16/70
RUNS 1 TO 9

SORBATE STAPH-AUREUS FDA-209
SORBENT SOIL MENDON SILT LOAM
TEMP 37.0 DEG. CENT.

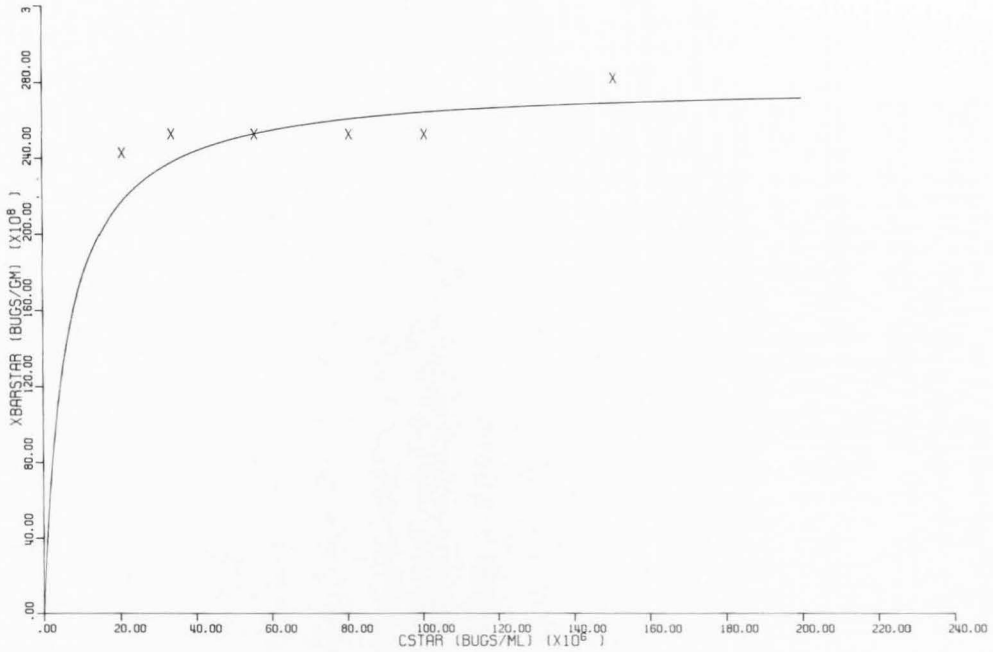
REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .936
RSQ = .982
Y INTERCEPT = 1/(ALPHA*XMAX) = .214552-03
SLOPE OF BEST FIT = .356697-10
ALPHA = .166251-06
XMAX = .280353+11

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

	RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
	1	01/16/70	.80000+08	.25000+11	.32000-02
	2	01/16/70	.55000+08	.25000+11	.22000-02
	3	01/16/70	.33000+08	.25000+11	.13200-02
	4	01/16/70	.20000+08	.24000+11	.83333-03
	8	01/20/70	.15000+09	.28000+11	.53571-02
	9	01/20/70	.10000+09	.25000+11	.40000-02
Δ	6	01/20/70	.24000+09	.24000+11	.10000-01
Δ	7	01/20/70	.20000+09	.23000+11	.86957-01
Δ	10	01/20/70	.28000+08	.32000+11	.87500-03

Δ Off the scale, therefore not shown in Figures



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

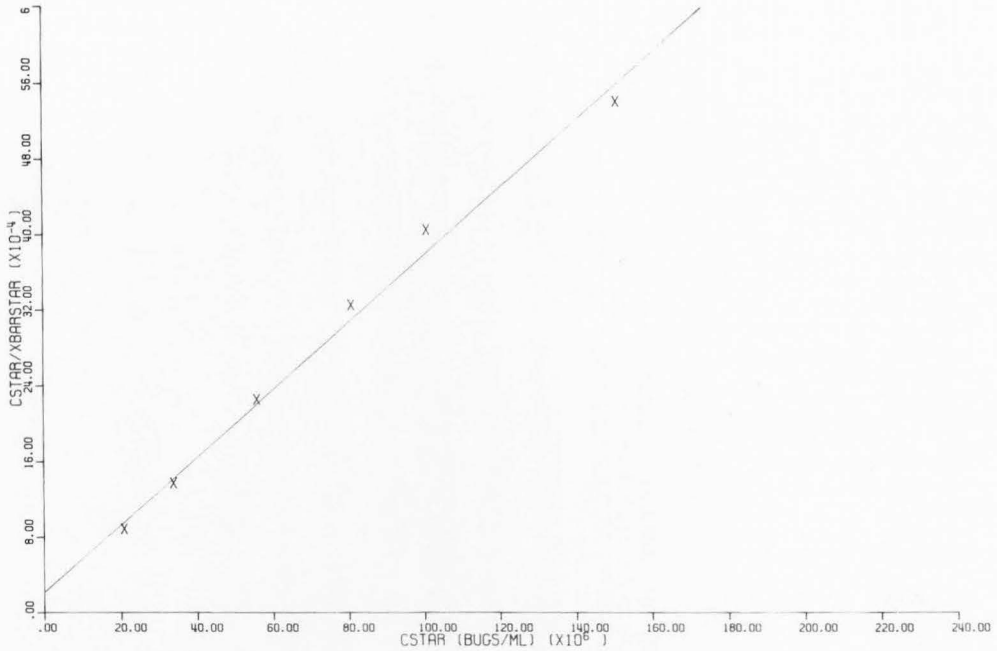
RUNS	1	SORBENT	MENDON SILT LOAM
TO	9	SORBATE	STAPH-AUREUS
TEMP	37.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	1	SORBENT	MENDON SILT LOAM
TO	9	SORBATE	STAPH-AUREUS
TEMP	37.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L

Appendix J

Bacterial Adsorption Isotherms (With SLS Competition)

Bacto-Peptone 0 GM/L

Sodium Chloride 0 GM/L

Sodium Lauryl Sulfate .05 GM/L

This appendix includes the bacterial adsorption isotherms obtained in the presence of SLS (.05 gram per liter). These isotherms were obtained at 10C, 20C, 27C, and 37C. A summary of results of these isotherms is presented in Table 1, p. 63.

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 11/06/69
RUNS 1 TO 22

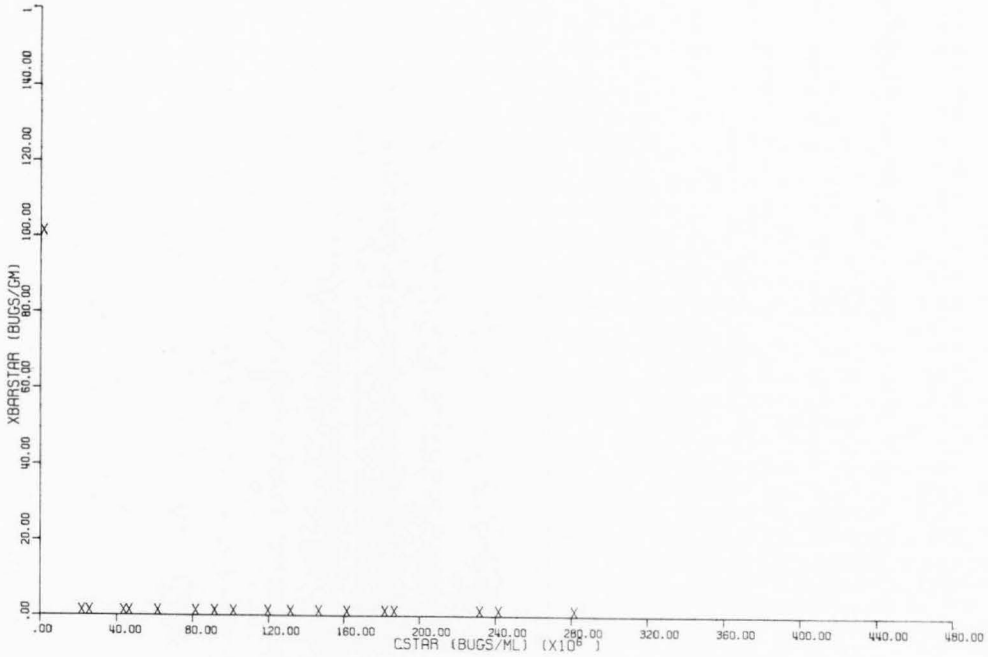
SORBATE STAPH-AUREUS FDA-209
SORBENT MENDON SILT LOAN .05LSG/L
TEMP 10.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .000
RSQ = .000
YINTERCEPT = 1/(ALPHA*XMAX) = .000000
SLOPE OF BEST FIT = .000000
ALPHA = .000000
XMAX = .000000

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
1	11/06/69	.900000+08	.000000	.000000
2	11/07/69	.100000+09	.000000	.000000
3	11/07/69	.800000+08	.000000	.000000
4	11/07/69	.600000+08	.000000	.000000
5	11/07/69	.420000+08	.000000	.000000
6	11/07/69	.240000+08	.000000	.000000
7	11/15/69	.900000+08	.000000	.000000
8	11/15/69	.800000+08	.000000	.000000
9	11/15/69	.450000+08	.000000	.000000
11	11/15/69	.200000+08	.000000	.000000
12	11/16/69	.185000+09	.000000	.000000
13	11/16/69	.160000+09	.000000	.000000
14	11/16/69	.145000+09	.000000	.000000
15	11/16/69	.130000+09	.000000	.000000
16	11/16/69	.118000+09	.000000	.000000
17	11/22/69	.280000+09	.000000	.000000
18	11/22/69	.240000+09	.000000	.000000
19	11/22/69	.230000+09	.000000	.000000
20	11/22/69	.180000+09	.000000	.000000
21	11/22/69	.160000+09	.000000	.000000
22	11/22/69	.000000	.100000+03	.000000



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

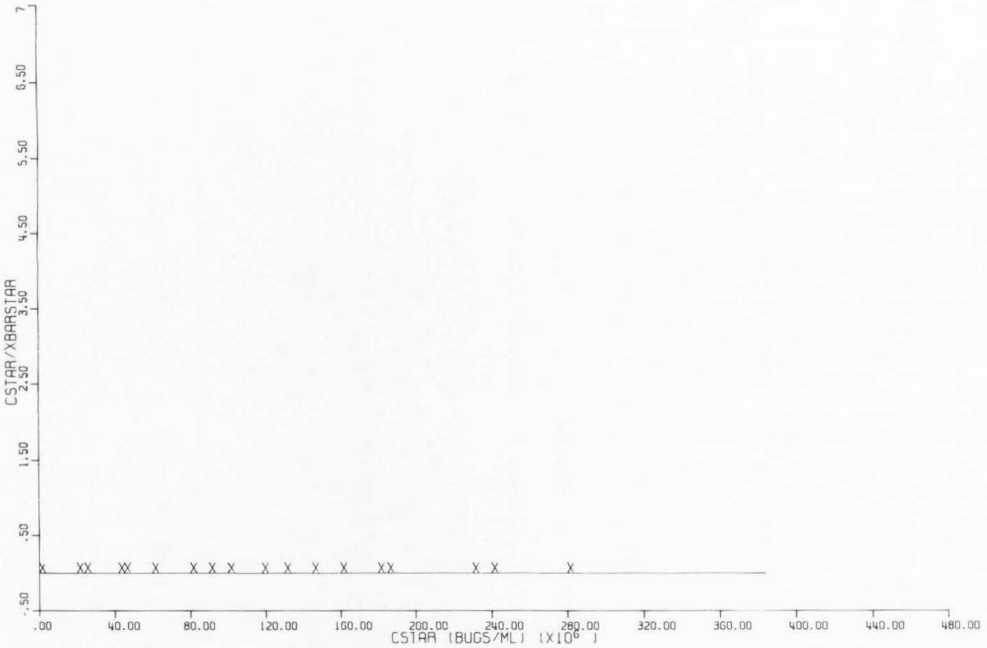
RUNS	1	SORBENT	MENDON SILT LOAM
TØ	22	SORBATE	STAPH-AUREUS
TEMP	10.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE .0 GM/L

SODIUM CHLORIDE .0 GM/L

SODIUM LAURYL SULFATE .05 GM/L



BACTERIA ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	1	SORBENT	MENDON SILT LOAM
TO	22	SORBATE	STAPH-AUREUS
TEMP	10.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE .0 GM/L

SODIUM CHLORIDE .0 GM/L

SODIUM LAURYL SULFATE .05 GM/L

[illegible] OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 12/03/69
RUNS 1 TO 14

SORBATE STAPH-AUREUS FDA-209
SORBENT MENDON SILT LOAM .01 LSG/L
TEMP 10.0 DEG. CENT.

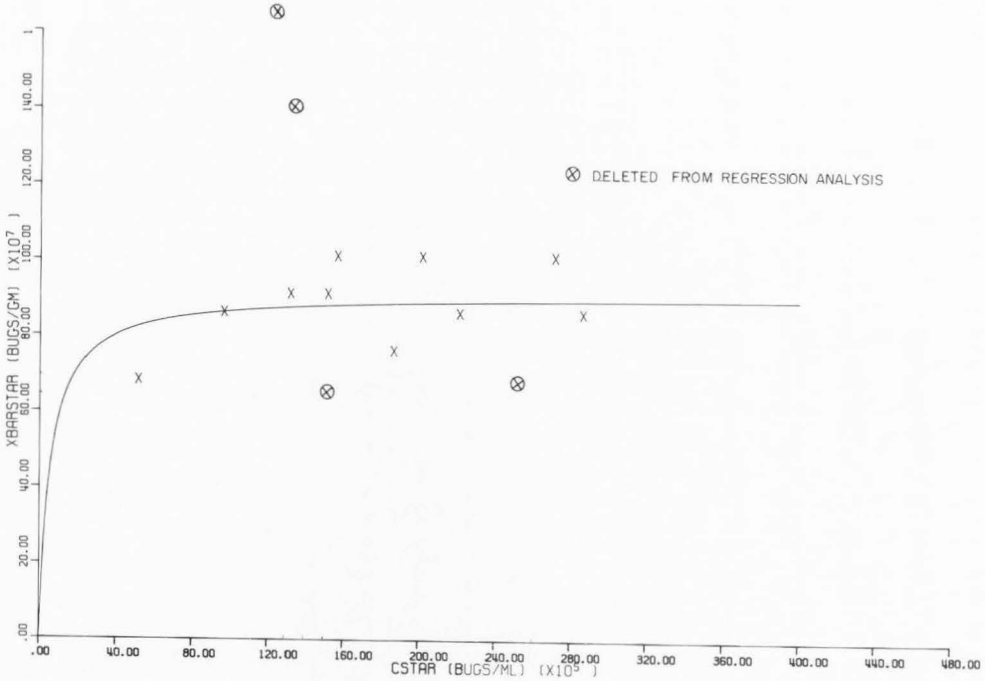
REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

N = 14
R = .98
VARIANCE OF X/(X/M+1/B) = .81[illegible]E-07
SLOPE OF BEST FIT = .10[illegible]E-02
ALPHA = .17[illegible]E-05
XMAX = .31[illegible]E+06

USED DATA EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

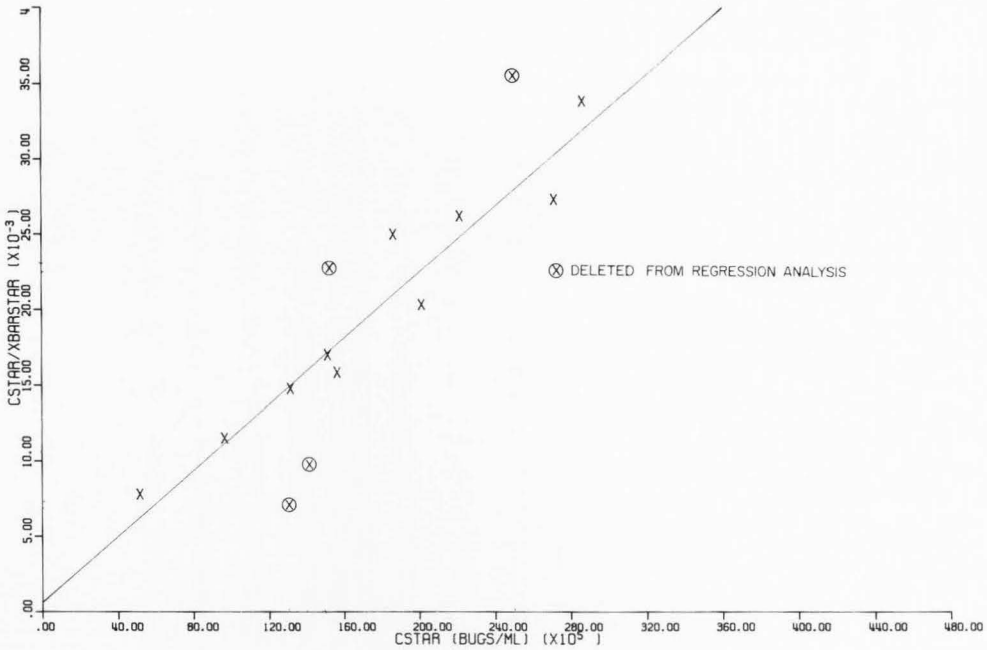
RUNS	DATE EXP #RUN	C*	X/M*	C*/X/M*
1	12/03/69	.16000+06	.16000+09	.10000-01
4	12/03/69	.60000+07	.60000+09	.10000-01
6	12/03/69	.15000+08	.75000+09	.20000-01
7	12/05/69	.22000+08	.85000+09	.25882-01
9	12/05/69	.26500+08	.85000+09	.31529-01
10	12/09/69	.95000+07	.85000+09	.11176-01
11	12/09/69	.13000+08	.90000+09	.14444-01
12	12/09/69	.14500+08	.10000+10	.14500-01
13	12/09/69	.20000+08	.10000+10	.20000-01
14	12/09/69	.27500+08	.10000+10	.27500-01
2	12/03/69	.14000+08	.14000+10	.10000-01
⊗ 3	12/03/69	.13000+08	.18000+10	.72222-02
⊗ 5	12/05/69	.15000+08	.65000+09	.23077-01
⊗ 8	12/05/69	.25000+08	.70000+09	.35714-01

⊗ Deleted from regression analysis but plotted in Figures



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

RUNS	1	SORBENT	MENDON SILT LOAM	COMPETITIVE EXPERIMENTS
TO	14	SORBATE	STAPH-AUREUS	BACTO PEPTONE .0 GM/L
TEMP	10.000			SODIUM CHLORIDE .0 GM/L
				SODIUM LAURYL SULFATE .01 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	1	SORBENT	MENDON SILT LOAM
TO	14	SORBATE	STAPH-AUREUS
TEMP	10.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE .01 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 02/40/70
RUNS 2 TO 14

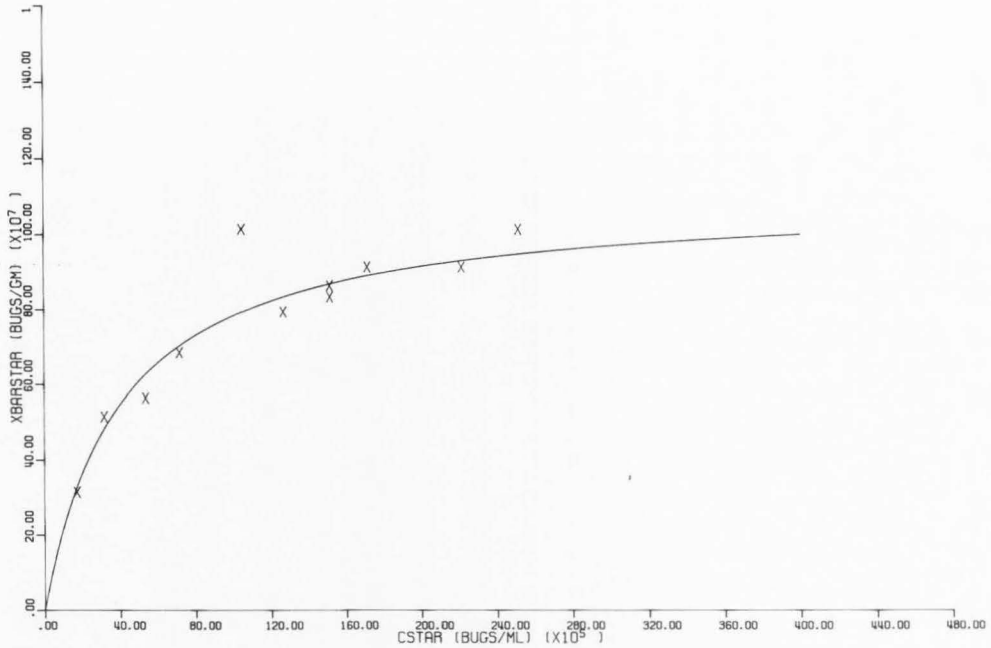
SORBATE STAPH-AUREUS FDA-209
SORBENT MENDON SILT LOAM 0.05LSG/L
TEMP 20.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .950
RSQ = .903
Y INTERCEPT = 1/(ALPHA*XMAX) = .268125-03
SLOPE OF BEST FIT = .949195-10
ALPHA = .754012-06
XMAX = .105352+11

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
2	02/40/70	.10000+09	.10000+11	.10000-01
3	02/07/70	.90000+08	.10600+11	.84906-02
4	02/04/70	.70000+08	.10000+11	.70000-02
5	02/04/70	.50000+08	.88000+10	.56818-02
7	02/05/70	.17000+09	.10000+11	.17000-01
8	02/05/70	.13500+09	.11000+11	.12273-01
9	02/05/70	.90000+08	.14000+11	.64286-02
10	02/05/70	.50000+08	.80000+10	.62500-02
12	02/06/70	.14000+09	.11000+11	.12727-01
13	02/06/70	.14000+09	.11000+11	.12727-01
13	02/06/70	.12500+09	.10000+11	.12500-01
14	02/06/70	.12000+09	.88000+10	.13636-01



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

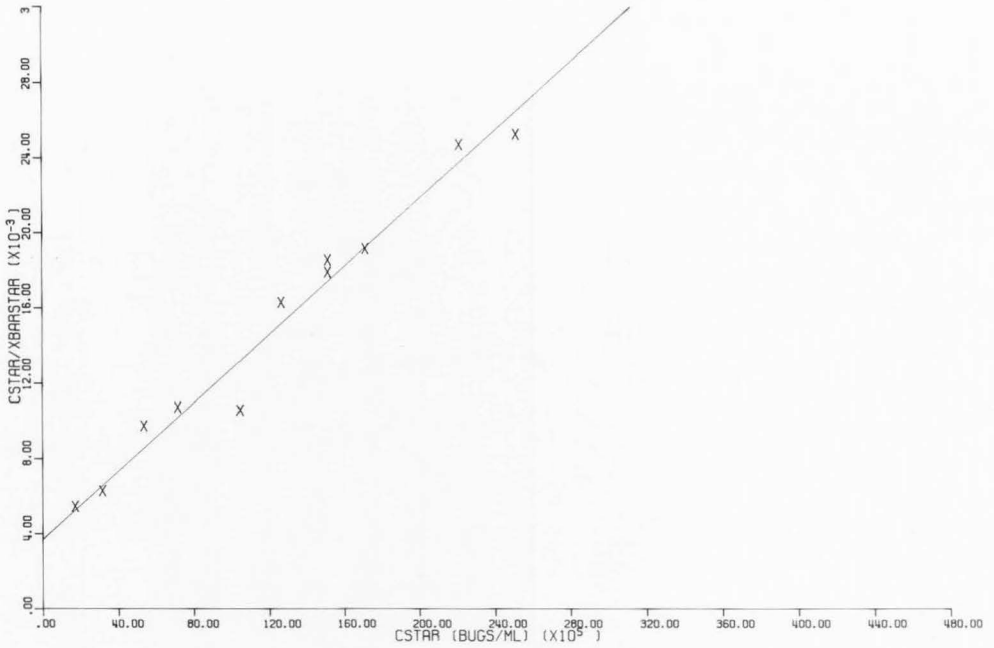
RUNS	2	SORBENT	MENDON SILT LOAM
TB	14	SORBATE	STAPH-AUREUS
TEMP	20.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE .0 GM/L

SODIUM CHLORIDE .0 GM/L

SODIUM LAURYL SULFATE .05 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	2	SORBENT	MENDON SILT LOAM
TO	14	SORBATE	STAPH-AUREUS
TEMP	20.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE .05 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 10/30/69
RUNS 2 TO 17

SORBATE STAPH-AUREUS
EDA-DIG
SORBENT MENDON SILT LOAM
.05 LSG/L
TEMP 27.0 DEG. CENT.

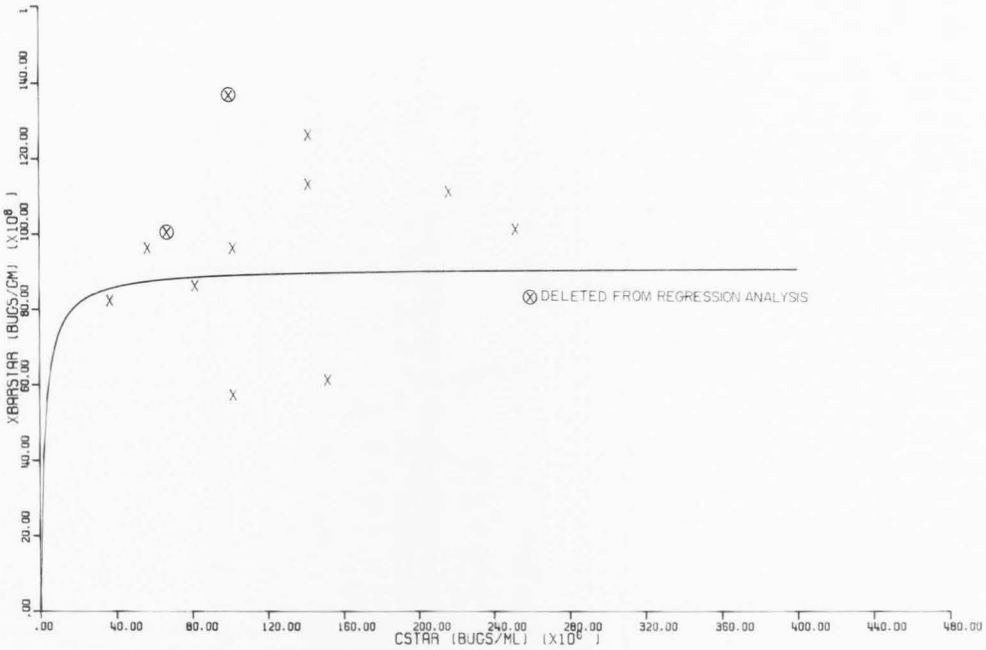
REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .929
RSQ = .687
YINTERCEPT = 1/(ALPHA*XMAX) = .263390-03
SLOPE OF BEST FIT = .194452-09
ALPHA = .405295-06
XMAX = .913840+10

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
2	10/30/69	.26000+09	.10000+11	.26000-01
3	10/30/69	.21550+09	.11000+11	.19545-01
4	10/30/69	.15000+09	.60000+10	.25000-01
5	11/04/69	.14000+09	.11200+11	.12500-01
12	11/04/69	.10000+09	.56000+10	.17857-01
13	12/11/69	.14000+09	.12500+11	.11200-01
14	12/11/69	.10000+09	.95000+10	.10526-01
15	12/11/69	.80000+08	.95000+10	.84118-02
16	12/11/69	.55000+08	.96000+10	.57895-02
17	12/11/69	.39000+08	.91000+10	.43210-02
⊗ 6	10/30/69	.10000+09	.13600+11	.73529-02
⊗ 11	11/04/69	.73000+08	.10000+11	.73000-02

⊗ Deleted from regression analysis but plotted in Figures



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

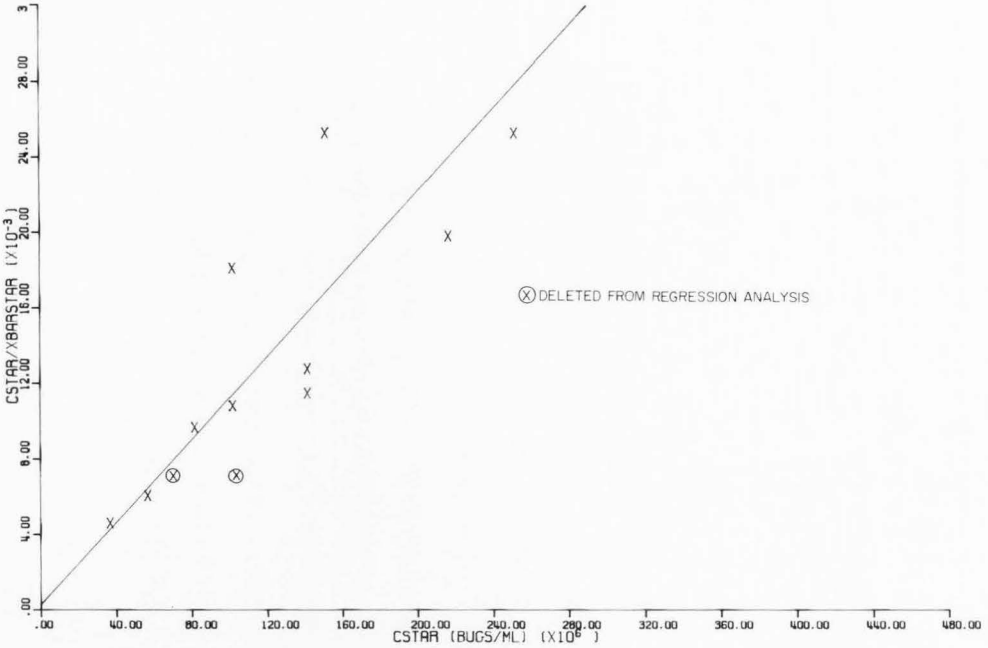
RUNS	2	SORBENT	MENDON SILT LOAM
TO	17	SORBATE	STAPH-AUREUS
TEMP	27.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE .0 GM/L

SODIUM CHLORIDE .0 GM/L

SODIUM LAURYL SULFATE .05 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	2	SORBENT	MENDON SILT LOAM
TO	17	SORBATE	STAPH-AUREUS
TEMP	27.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE .0 GM/L
SODIUM CHLORIDE .0 GM/L
SODIUM LAURYL SULFATE .05 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 01/15/70
RUNS 7 TO 15

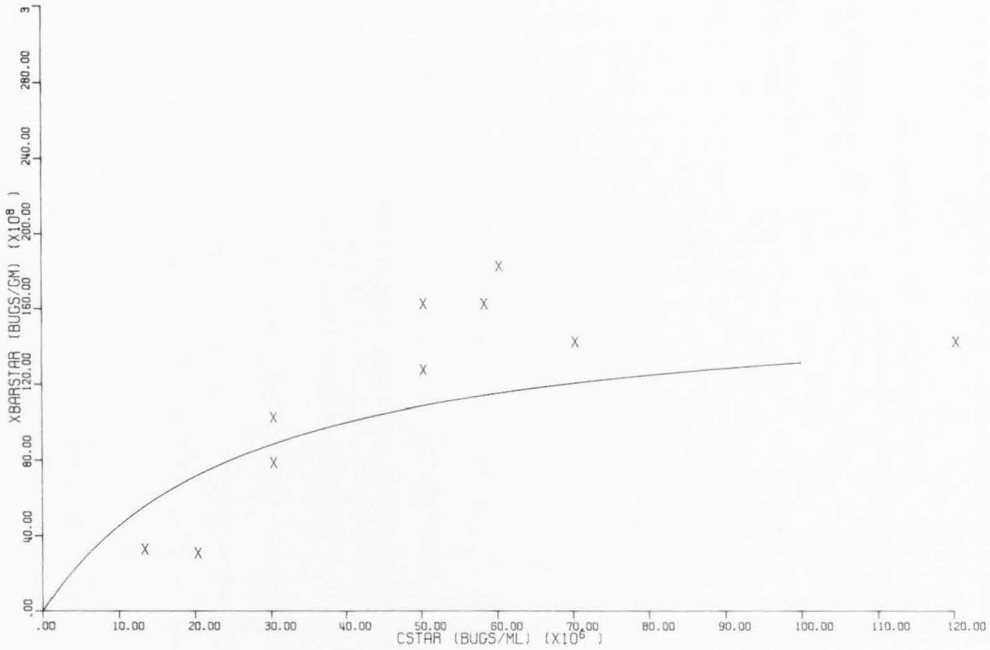
SORBATE STAPH-AUREUS FDA-209
SORBENT MENDON SILT LOAM 0.05LSG/L
TEMP 37.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .945
RSQ = .892
YINTERCEPT = 1/(ALPHA*XMAX) = .14286E-03
SLOPE OF BEST FIT = .65089D-10
ALPHA = .45606E-06
XMAX = .15336E+11

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

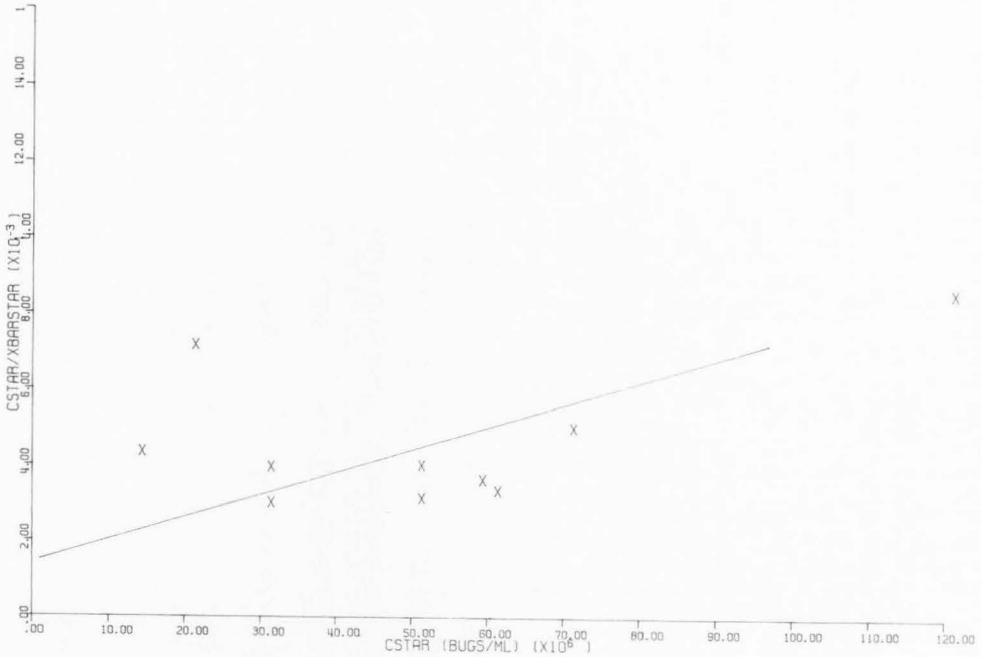
RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
7	01/15/70	.50000+08	.16000+11	.31250-02
8	01/15/70	.50000+08	.12500+11	.40000-02
9	01/15/70	.60000+08	.18000+11	.33333-02
10	01/15/70	.58000+08	.16000+11	.36250-02
11	01/15/70	.70000+08	.14000+11	.50000-02
13	03/12/70	.10000+08	.11500+11	.86957-03
14	03/12/70	.30000+08	.13500+11	.22222-02
15	03/12/70	.50000+08	.14000+11	.35714-02



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

RUNS	1	SORBENT	MENDON SILT LOAM
TØ	11	SORBATE	STAPH-AUREUS
TEMP	37.000		

COMPETITIVE EXPERIMENTS
BACTO PEPTONE .0 GM/L
SODIUM CHLORIDE .0 GM/L
SODIUM LAURYL SULFATE .05 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	1	SORBENT	MENDON SILT LOAM
TO	11	SORBATE	STAPH-AUREUS
TEMP	37.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE .0 GM/L

SODIUM CHLORIDE .0 GM/L

SODIUM LAURYL SULFATE .05 GM/L

Appendix K

Bacterial Adsorption Isotherms (With Peptone Competition)

Bacto-Peptone 3.8 GM/L

Sodium Chloride 0 GM/L

Sodium Lauryl Sulfate 0 GM/L

Bacterial uptake isotherms using peptone (3.8 grams per liter) as a competitive sorbate are shown in this appendix. Results of these isotherms are summarized in Table 1, p. 63.

ESTIMATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

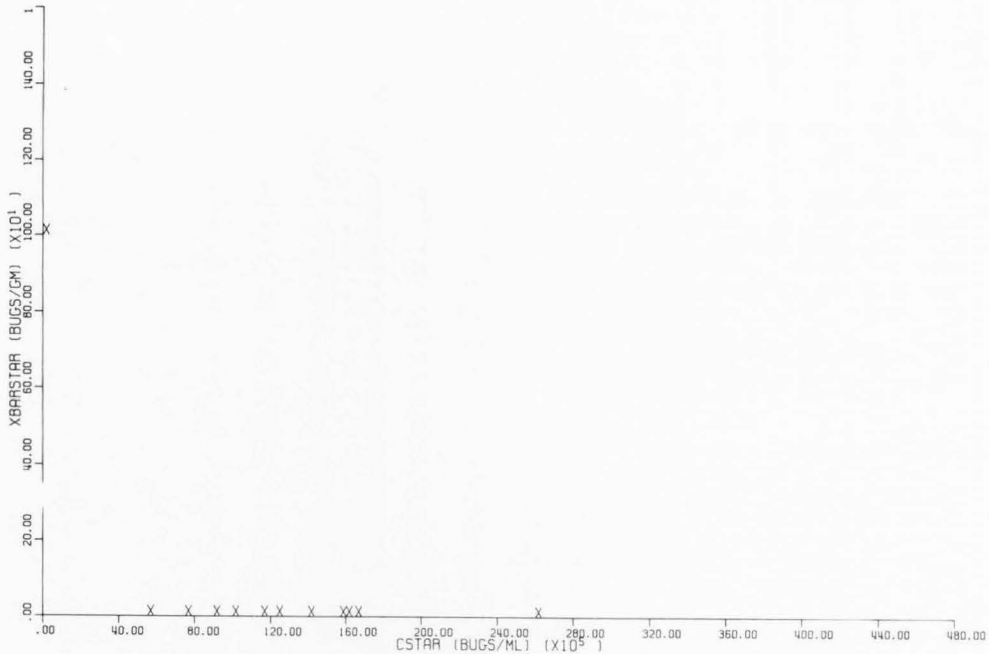
DATE OF RUN 1 = 12/10/69 SORBATE STAPH-AUREUS
RUNS 2 TO 21 FDA-209
SORBENT MENDON SILT LOAM
3.96PEPTONE/L
TEMP 10.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .[illegible]
RSQ = .[illegible]
Y-INTERCEPT = 1/(ALPHA*XMAX) = .[illegible]
SLOPE OF BEST FIT = .[illegible]
ALPHA = .[illegible]
XMAX = .[illegible]

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
2	12/10/69	.17000+09	.00000	.00000
3	12/10/69	.14000+09	.00000	.00000
4	12/10/69	.16000+08	.00000	.00000
5	12/10/69	.26000+08	.00000	.00000
12	12/16/69	.55000+07	.00000	.00000
14	12/16/69	.12300+08	.00000	.00000
16	12/16/69	.15700+08	.00000	.00000
17	12/18/69	.75000+07	.00000	.00000
18	12/18/69	.93000+07	.00000	.00000
19	12/18/69	.11500+08	.00000	.00000
20	12/18/69	.16500+08	.00000	.00000
21	12/18/69	.00000	.[illegible]+04	.00000



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

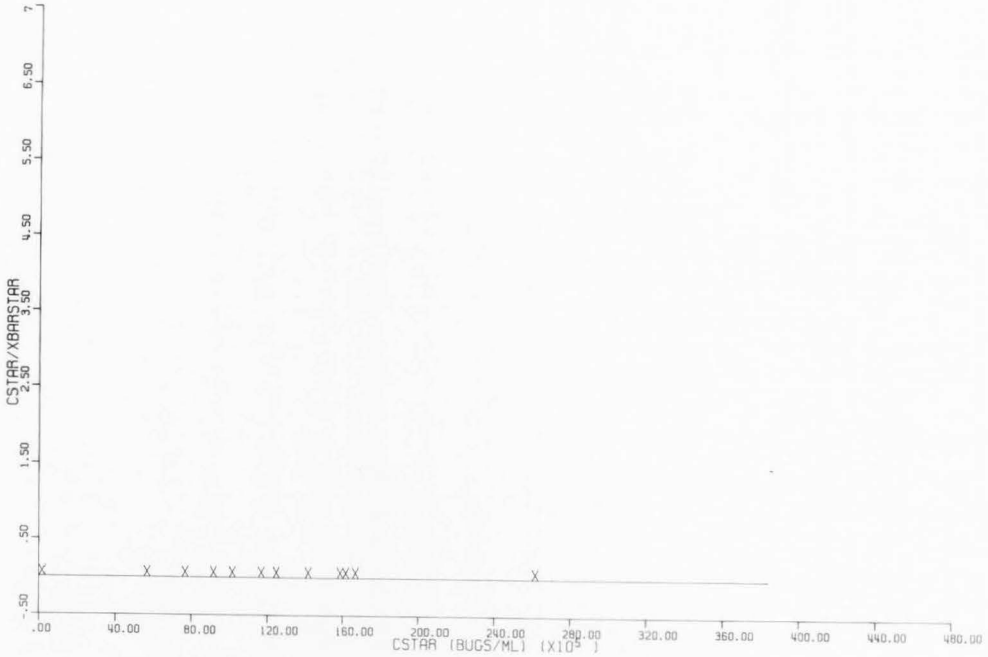
RUNS	2	SORBENT	MENDON SILT LOAM
TO	21	SORBATE	STAPH-AUREUS
TEMP	10.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 3.8 GM/L

SODIUM CHLORIDE .0 GM/L

SODIUM LAURYL SULFATE .0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS LINEARIZED LANGMUIR ISOTHE

RUNS	2	SORBENT	MENDON SILT LOAM
TO	21	SORBATE	STAPH-AUREUS
TEMP	10.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 3.8 GM/L

SODIUM CHLORIDE .0 GM/L

SODIUM LAURYL SULFATE .0 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 02/08/70
RUNS 2 TO 14

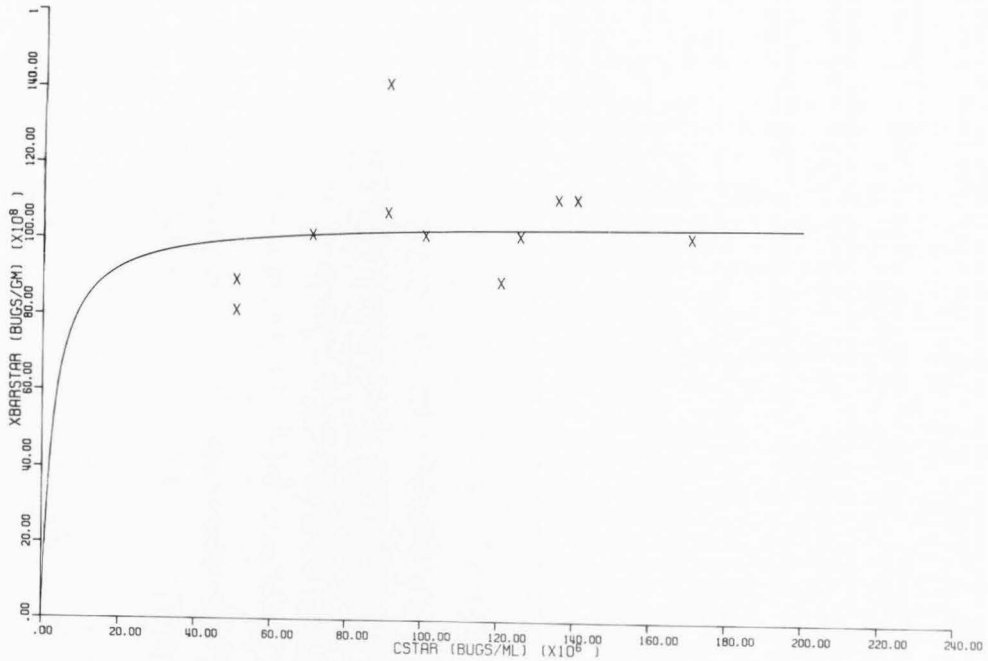
SORBATE STAPH-AUREUS FDA-209
SORBENT MENDON SILT LOAM 3.8GPEPTONE/L
TEMP 20.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .966
RSQ = .932
Y-INTERCEPT = 1/(ALPHA*XMAX) = .369309-02
SLOPE OF BEST FIT = .306355-09
ALPHA = .345620-06
XMAX = .110732+10

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
2	02/08/70	.52000+07	.55000+09	.94545-02
3	02/08/70	.30000+07	.50000+09	.60000-02
4	02/08/70	.15500+07	.30000+09	.51667-02
5	02/10/70	.17000+08	.90000+09	.18889-01
7	02/10/70	.15000+08	.82000+09	.18293-01
8	02/10/70	.12500+08	.78000+09	.16026-01
9	02/10/70	.70000+07	.67000+09	.10448-01
11	02/12/70	.10300+08	.10000+10	.10300-01
12	02/12/70	.15000+08	.85000+09	.17647-01
13	02/12/70	.22000+08	.90000+09	.24444-01
14	02/12/70	.25000+09	.10000+10	.25000-01



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

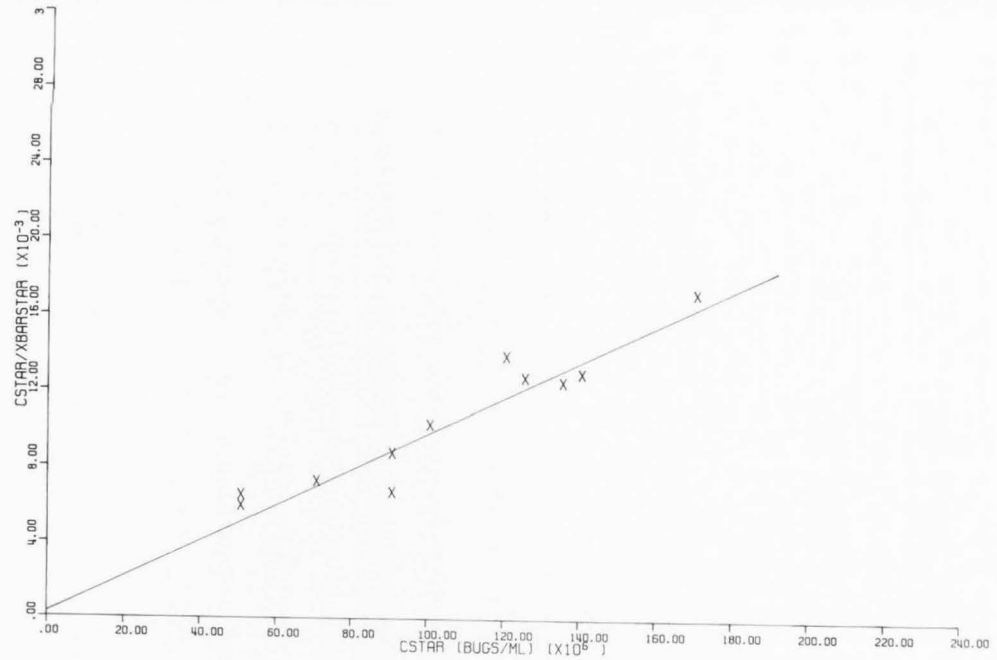
RUNS	2	SORBENT	HENDON SILT LOAM
TO	14	SORBATE	STAPH-AUREUS
TEMP	20.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 3.8 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	2	SORBENT	MENDON SILT LOAM
TO	14	SORBATE	STAPH-AUREUS
TEMP	20.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 3.8 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 12/02/69
RUNS 2 TO 15

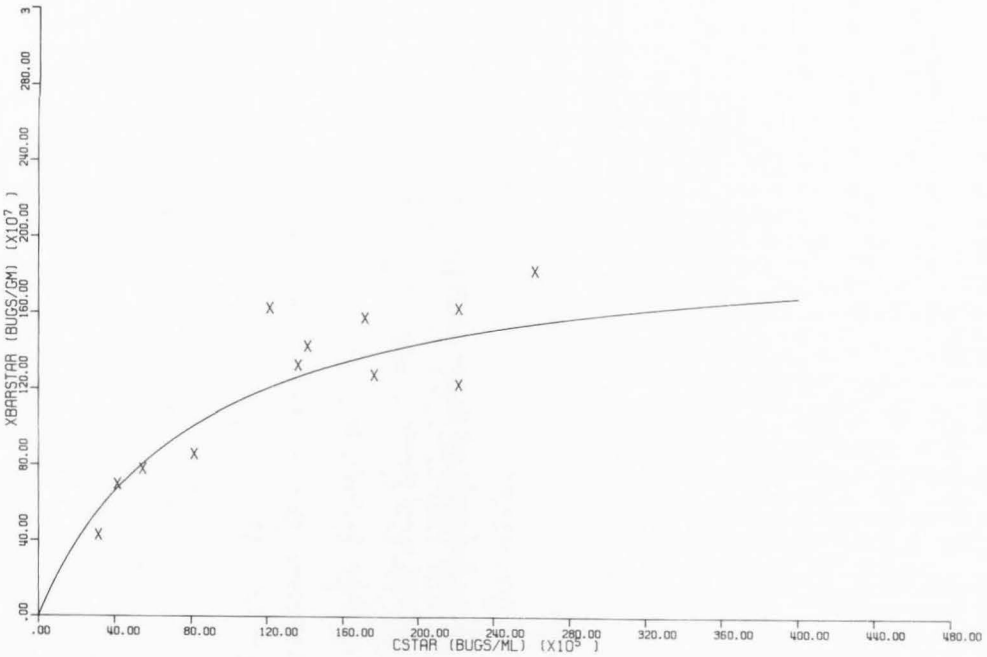
SORBATE STAPH-AUREUS FDA-209
SORBENT MENDON SILT LOAM
3.8GPEPTONE/L
TEMP 27.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .879
RSQ = .772
YINTERCEPT = 1/(ALPHA*XMAX) = .41057E-02
SLOPE OF BEST FIT = .48866E-09
ALPHA = .11902D-06
XMAX = .20464E+10

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
2	12/02/69	.80000E+07	.83000E+09	.96386E-02
3	12/02/69	.53000E+07	.75000E+09	.70667E-02
4	12/05/69	.40000E+07	.67000E+09	.59701E-02
5	12/02/69	.30000E+07	.40000E+09	.75000E-02
7	12/04/69	.13500E+08	.13000E+10	.10385E-01
8	12/04/69	.17000E+08	.15500E+10	.10968E-01
9	12/04/69	.22000E+08	.16000E+10	.13750E-01
10	12/04/69	.26000E+08	.18000E+10	.14444E-01
12	12/06/69	.12000E+08	.16000E+10	.75000E-02
13	12/06/69	.14000E+08	.14000E+10	.10000E-01
14	12/06/69	.17500E+08	.12500E+10	.14000E-01
15	12/06/69	.22000E+08	.12000E+10	.18333E-01



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

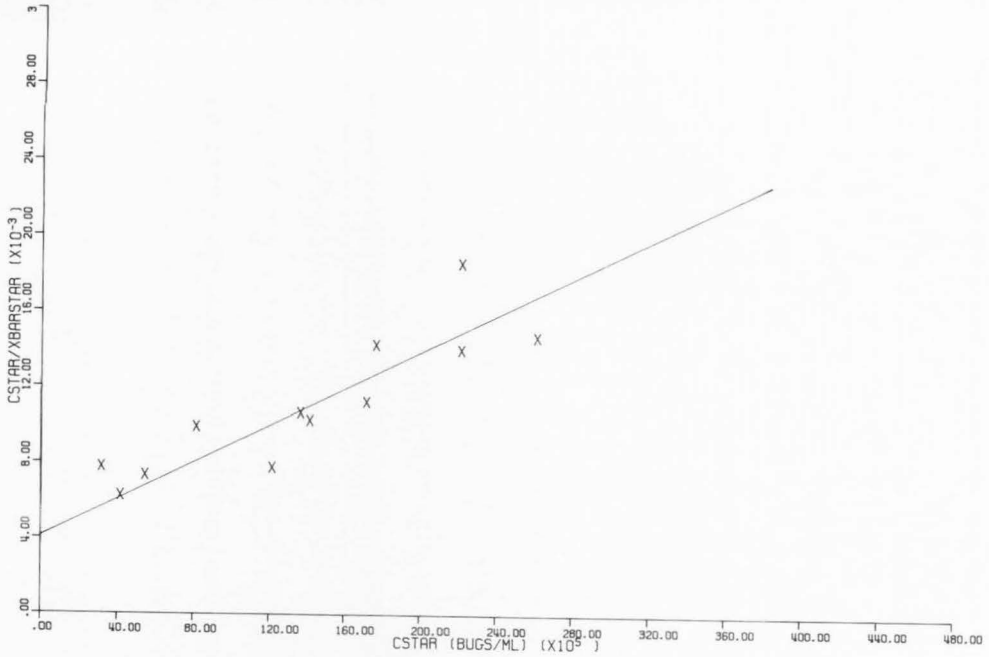
RUNS	2	SORBENT	MENDON SILT LOAM
TO	15	SORBATE	STAPH-AUREUS
TEMP	27.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 3.8 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	2	SORBENT	MENDON SILT LOAM
TO	15	SORBATE	STAPH-AUREUS
TEMP	27.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 3.8 GM/L

SODIUM CHLORIDE 0 GM/L

SODIUM LAURYL SULFATE 0 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

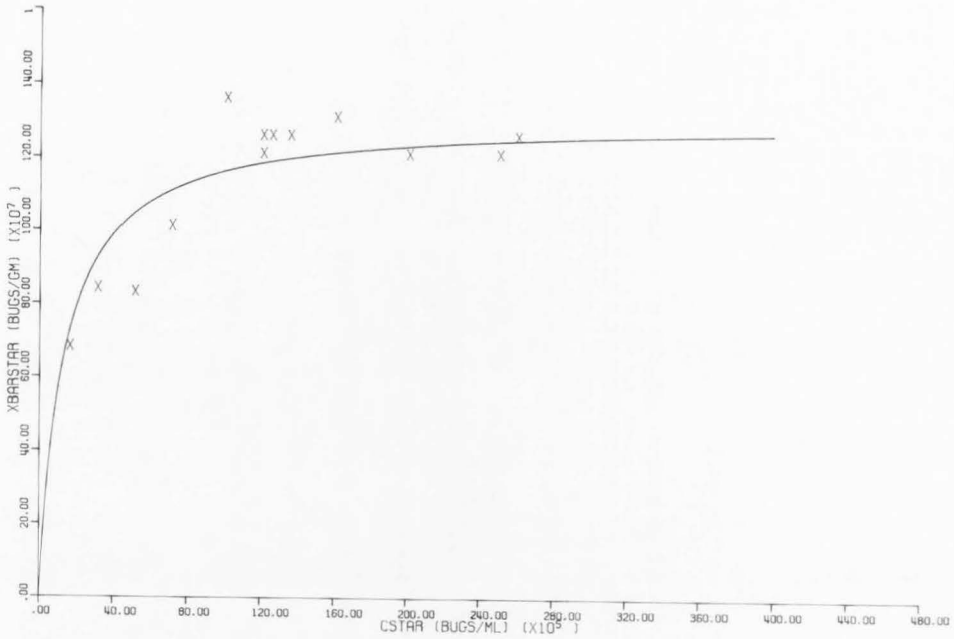
DATE OF RUN 1 = 01/07170 SORBATE STAPH-AUREUS
RUNS 4 TO 19 FDA-209
SORBENT HENDON SILT 30AM
3.REPEPTONE/L
TEMP 37.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .993
RSQ = .985
YINTERCEPT = 1/(ALPHA*XMAX) = .998122-03
SLOPE OF BEST FIT = .760797-08
ALPHA = .762229-06
XMAX = .131441+10

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
4	01/07170	.26000+08	.12500+10	.20800-01
5	01/0717	.25000+08	.12000+10	.20833-01
8	01/09/70	.10000+08	.13500+10	.74074-02
9	01/09/70	.12000+08	.12500+10	.96000-02
10	01/09/70	.12500+08	.12500+10	.10000-01
12	01/14/70	.12000+08	.12000+10	.10000-01
13	01/14/70	.13500+09	.12500+10	.10800-01
14	01/14/70	.16000+08	.13000+10	.12308-01
15	01/14/70	.20000+08	.12000+10	.16667-01
16	02/26/70	.15000+07	.67000+09	.22388-02
17	02/26/70	.30000+07	.83000+09	.36145-02
18	02/26/70	.50000+07	.82000+09	.60976-02
19	02/26/7	.70000+07	.10000+10	.70000-02

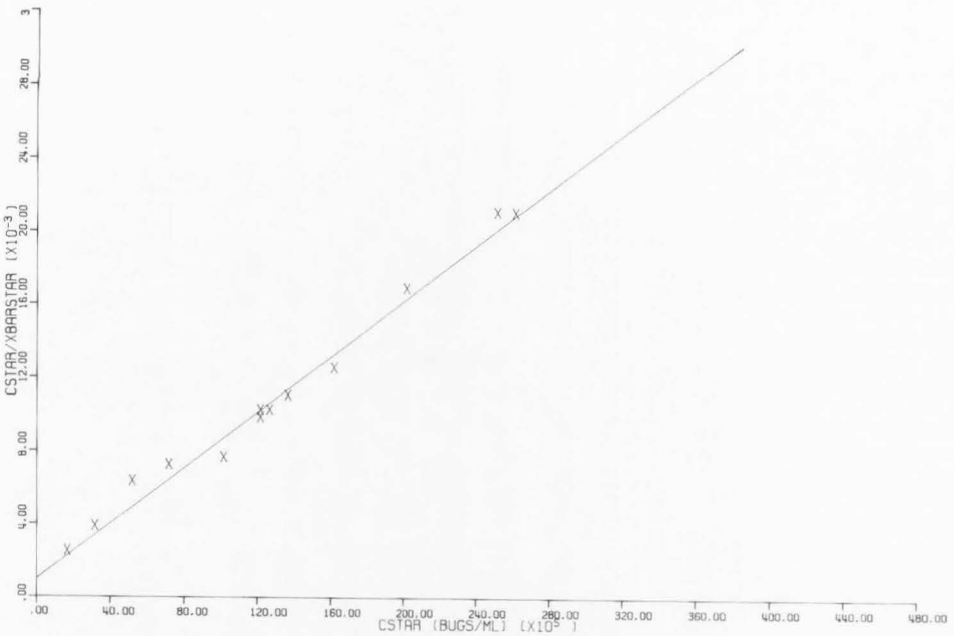


BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

RUNS	4	SORBENT	MENDON SILT LOAM
TO	19	SORBATE	STAPH-AUREUS
TEMP	37.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 3.8 GM/L
SODIUM CHLORIDE .0 GM/L
SODIUM LAURYL SULFATE .0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	4	SORBENT	MENDON SILT 30AM
TO	19	SORBATE	STAPH-AUREUS
TEMP	37.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 3.8 GM/L

SODIUM CHLORIDE .0 GM/L

SODIUM LAURYL SULFATE .0 GM/L

Appendix L

Bacterial Adsorption Isotherms (With NaCl Competition)

Bacto-Peptone 0 GM/L

Sodium Chloride 30 GM/L

Sodium Lauryl Sulfate 0 GM/L

This appendix includes the isotherms obtained at 10C, 20C, 27C, and 37C, using NaCl (30 grams per liter) as a competitive sorbate. The summary of results of these isotherms is shown in Table 1, p. 63.

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 11/05/69
RUNS 2 TO 12

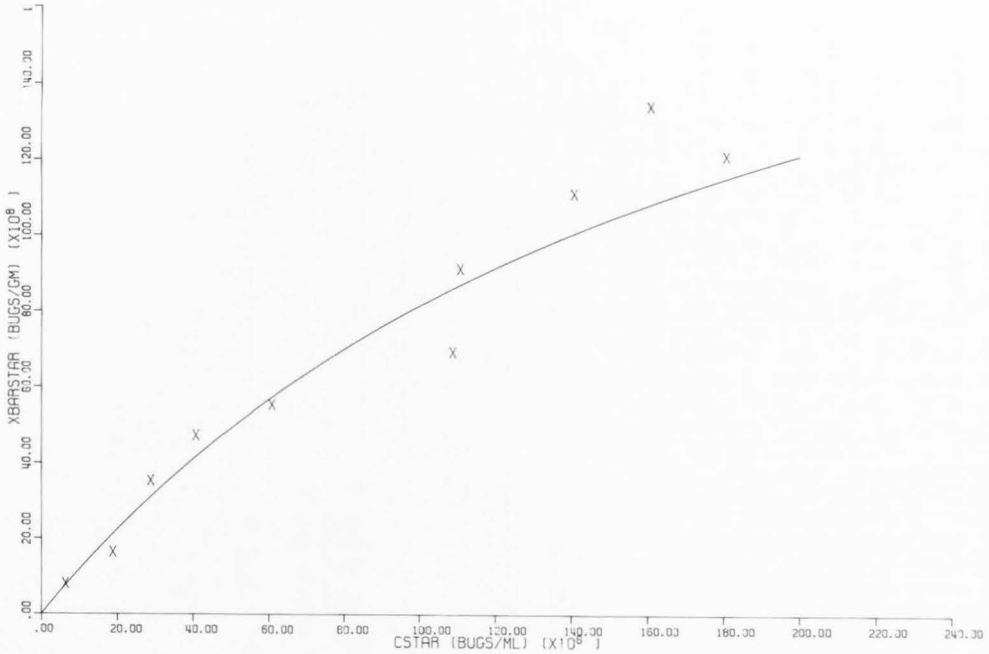
SORBATE STAPH-AUREUS FDA-209
SORBENT MENDON SILT LOAM 3PCTNACL
TEMP 10.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .737
RSQ = .543
Y INTERCEPT = 1/(ALPHA*XMAX) = .805940-02
SLOPE OF BEST FIT = .419580-10
ALPHA = .520E10-08
XMAX = .238334+11

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
2	11/05/69	.18000+09	.12000+11	.15000-01
3	11/05/69	.16000+09	.13300+11	.12030-01
4	11/05/69	.14000+09	.11000+11	.12727-01
5	11/05/69	.11000+09	.90000+10	.12222-01
6	11/05/69	.10800+09	.68000+10	.15882-01
8	11/07/69	.60000+08	.54000+10	.11111-01
9	11/07/69	.40000+08	.46000+10	.86957-02
10	11/07/69	.28000+08	.34000+10	.82353-02
11	11/07/69	.18000+08	.15000+10	.12000-01
12	11/07/69	.55000+07	.66000+09	.83333-02



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

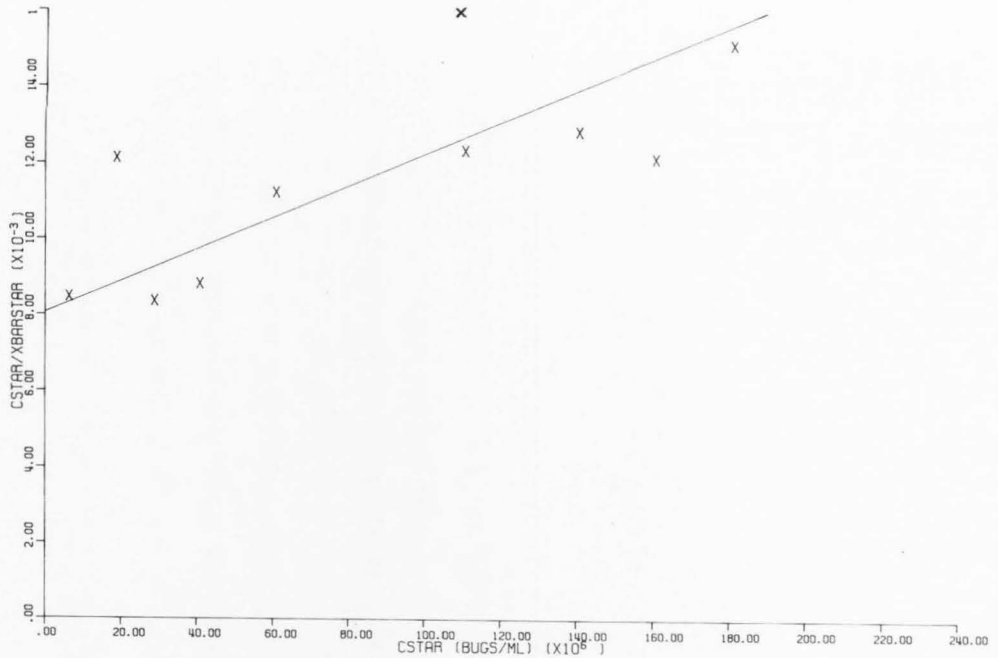
RUNS	2	SORBENT	MENDON SILT LOAM
TO	12	SORBATE	STAPH-AUREUS
TEMP	10.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE .0 GM/L

SODIUM CHLORIDE 3.0 GM/L

SODIUM LAURYL SULFATE .0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	2	SORBENT	MENDON SILT LOAM	COMPETITIVE EXPERIMENTS
TO	12	SORBATE	STAPH-AUREUS	BACTO PEPTONE .0 GM/L
TEMP	10.000			SODIUM CHLORIDE 3.0 GM/L
				SODIUM LAURYL SULFATE .0 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 02/16/70
RUNS 1 TO 14

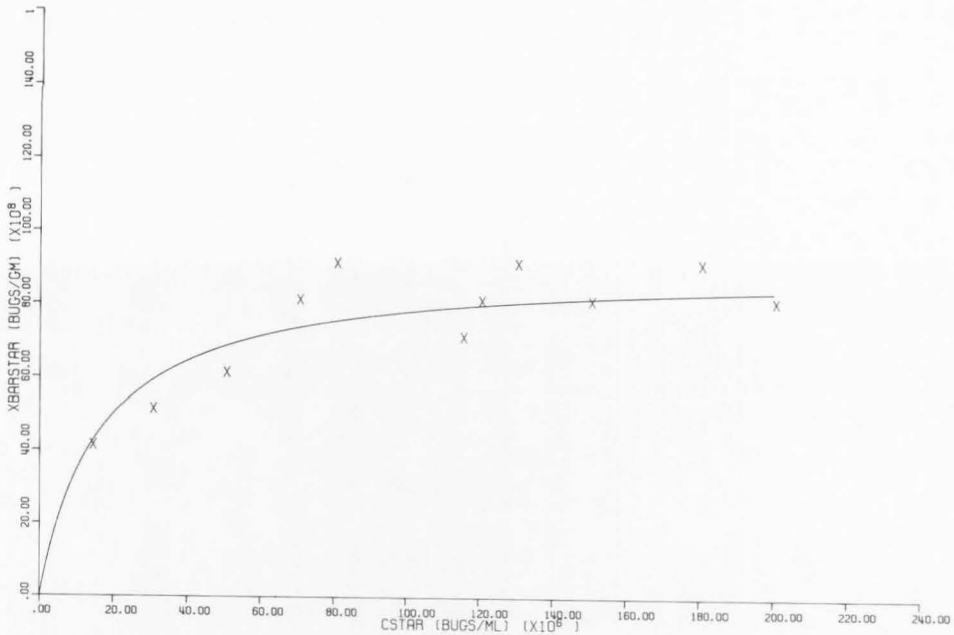
SORBATE STAPH-AUREUS EDA-209
SORBENT MENDON SILT LOAM
3PCTNACL
TEMP 20.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .992
RSQ = .983
YINTERCEPT = 1/(ALPHA*XMAX) = .180048-02
SLOPE OF BEST FIT = .109975-00
ALPHA = .610812-07
XMAX = .909294+10

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
1	02/16/70	.70000+08	.80000+10	.87500-02
2	02/16/70	.50000+08	.60000+10	.83333-02
3	02/16/70	.30000+08	.50000+10	.60000-02
4	02/16/70	.13800+08	.40000+10	.34500-02
7	02/18/70	.23000+09	.80000+10	.28750-01
8	02/18/70	.18000+09	.90000+10	.20000-01
9	02/18/70	.13000+09	.90000+10	.14444-01
11	02/20/70	.15000+09	.80000+10	.18750-01
12	02/20/70	.12000+09	.80000+10	.15000-01
13	02/20/70	.11500+09	.70000+10	.15429-01
14	02/20/70	.80000+09	.90000+10	.88889-02



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

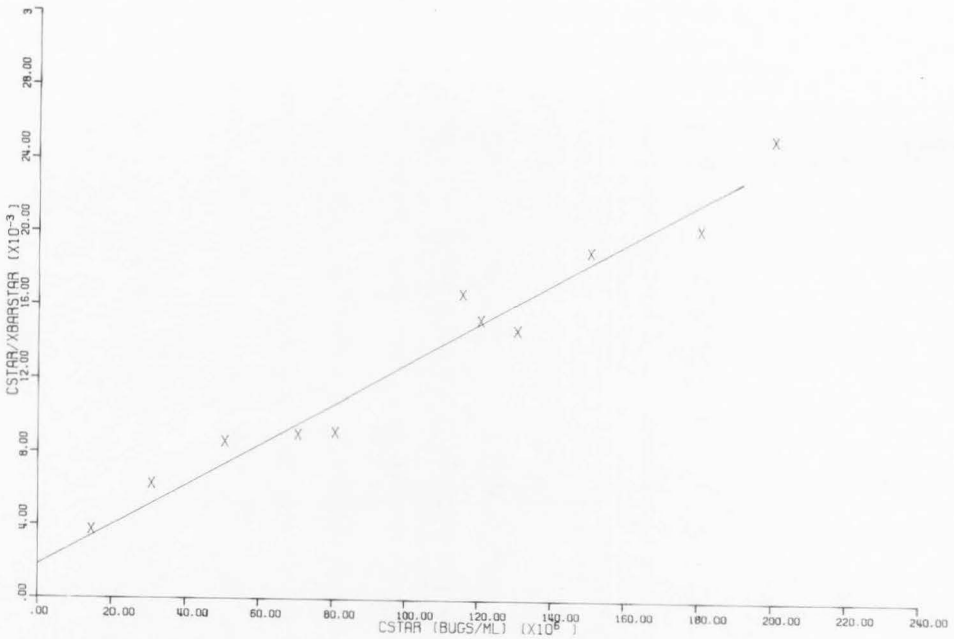
RUNS	1	SORBENT	MENDON SILT LOIM
TO	14	SORBATE	STAPH-AUREUS
TEMP	20.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 3.0 GM/L

SODIUM LAURYL SULFATE 0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	1	SORBENT	HENDON SILT LOAM
TO	14	SORBATE	STAPH-AUREUS
TEMP	20.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE 0 GM/L

SODIUM CHLORIDE 3.0 GM/L

SODIUM LAURYL SULFATE 0 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 10/25/69
RUNS 3 TO 11

SORBATE STAPH-AUREUS FDA-209
SORBENT MENDON SILT LOAM
3 PCT NACL
TEMP 27.0 DEG. CENT.

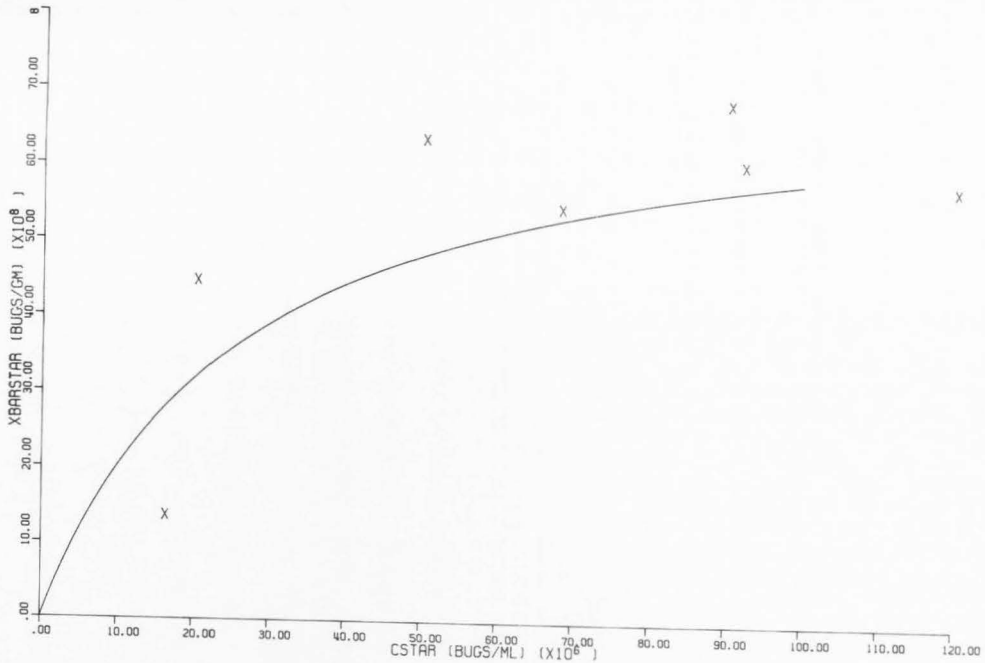
REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .918
R2 = .668
Y-INTERCEPT = 1/(ALPHA*XMAX) = .350565-02
SLOPE OF BEST FIT = .139447-09
ALPHA = .775653-07
XMAX = .738295+10

BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

	RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
	3	10/25/69	.12000+09	.57000+10	.21053-01
	4	10/25/69	.30000+08	.68000+10	.13235-01
	5	10/25/69	.50000+08	.63000+10	.79365-02
	8	10/29/69	.92000+08	.60000+10	.15333-01
	9	10/29/69	.68000+08	.54000+10	.12593-01
	10	10/29/69	.20000+08	.44000+10	.45455-02
	11	10/29/69	.16000+08	.13000+10	.12308-01
Δ	1	10/25/69	.26700+09	.42000+10	.63571-01
Δ	2	10/25/69	.14800+09	.80000+10	.18500-01
Δ	7	10/29/69	.21500+09	.92000+10	.23370-01

Δ Off the scale, therefore not shown in Figures



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

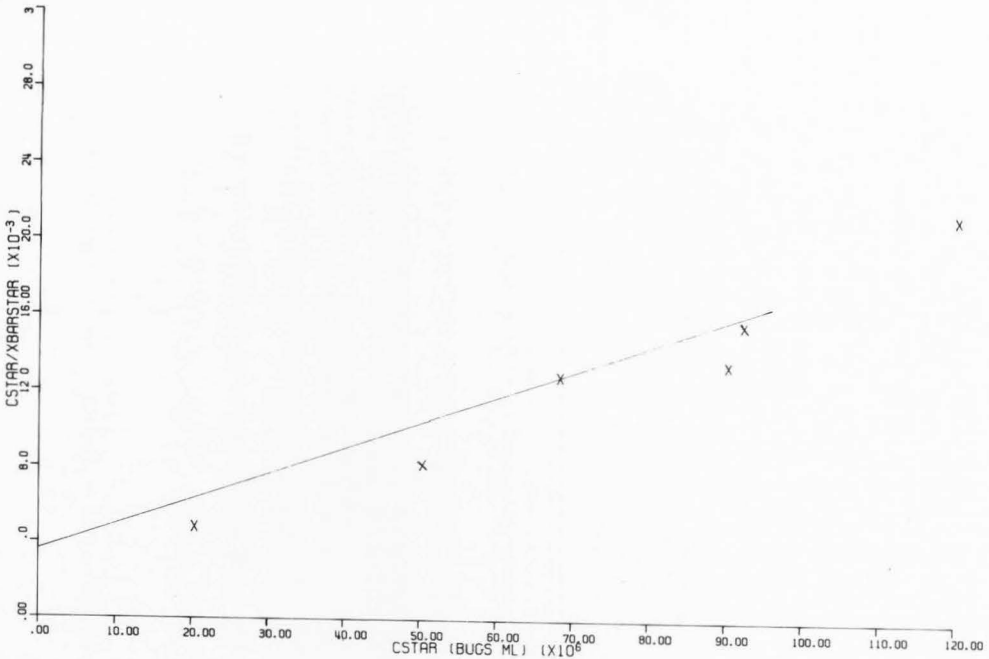
RUNS	3	SORBENT	MENDON SILT LOAM
TO	11	SORBATE	STAPH-AUREUS
TEMP	27.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE .0 GM/L

SODIUM CHLORIDE .30 GM/L

SODIUM LAURYL SULFATE .0 GM/L



BAC ER AL ADSORPTION EXPERIME TS - LINEARIZED LANGMUIR ISOTHE

RUNS	3	SORBENT	MENDON SILT LOAM	COMPETITIVE EXPERIMENTS
TØ	11	SORBATE	STAPH-AUREUS	BACTO PEPTONE .0 GM/L
TEMP	27.000			SODIUM CHLORIDE 3.0 GM/L
				SODIUM LAURYL SULFATE .0 GM/L

DETERMINATION OF ALPHA AND XMAX BY REGRESSION ANALYSIS OF LINEARIZED LANGMUIR ISOTHERM

DATE OF RUN 1 = 03/02/70
RUNS 2 TO 14

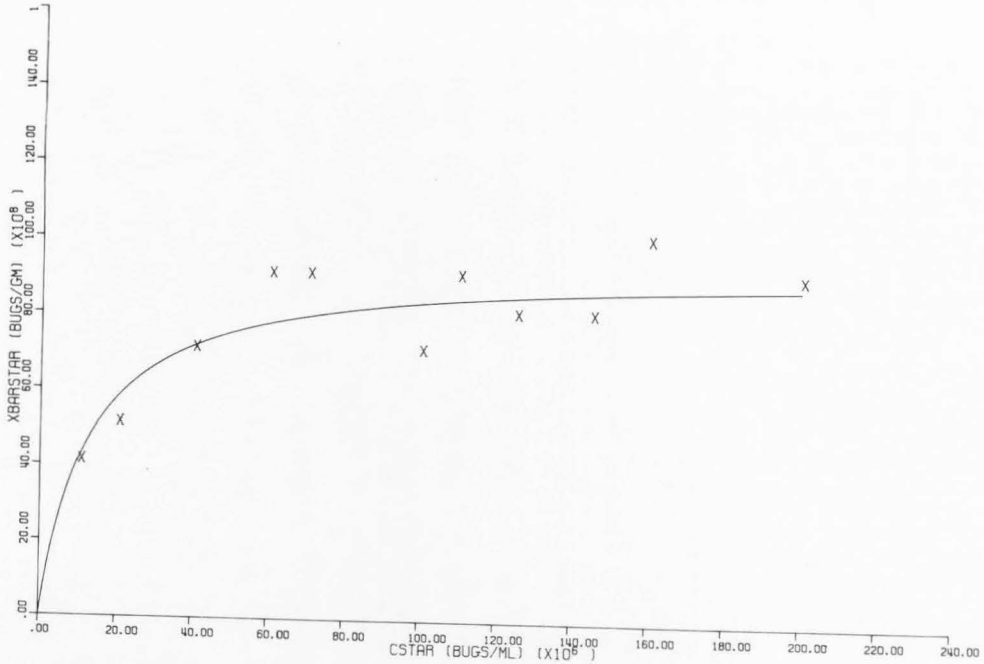
SORBATE STAPH-AUREUS FDA-209
SORBENT MENDON SILT LOAM 3PCTNCAL
TEMP 37.0 DEG. CENT.

REGRESSION ANALYSIS OF LINEARIZED ISOTHERM - RESULTS

R = .979
RSQ = .959
YINTERCEPT = 1/(ALPHA*XMAX) = .134613-02
SLOPE OF BEST FIT = .106088-09
ALPHA = .788098-07
XMAX = .942614+10

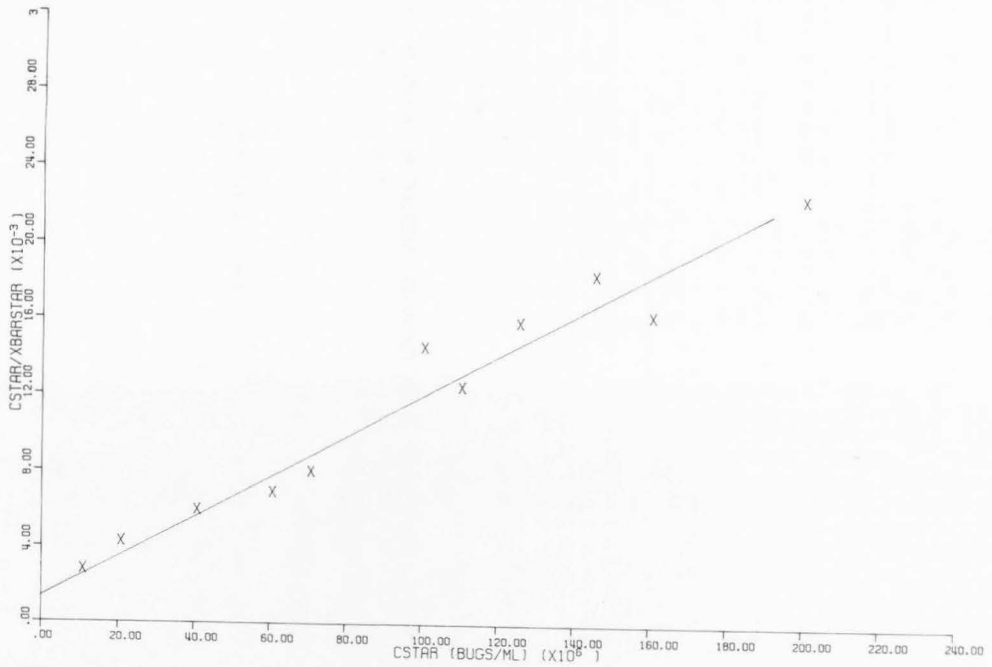
BASED UPON EQUILIBRIUM DATA FROM INDIVIDUAL RUNS

RUNS	DATE EXP BEGUN	C*	XBAR*	C*/XBAR*
2	03/02/70	.60000+08	.90000+10	.66667-02
3	03/02/70	.40000+08	.70000+10	.57143-02
4	03/02/70	.20000+08	.50000+10	.40000-02
5	03/02/70	.10000+08	.40000+10	.25000-02
7	03/05/70	.20000+09	.90000+10	.22222-01
8	03/05/70	.16000+09	.10000+11	.16000-01
9	03/05/70	.12500+09	.80000+10	.15625-01
10	03/05/70	.14500+09	.80000+10	.18125-01
12	03/10/70	.11000+09	.90000+10	.12222-01
13	03/10/70	.10000+09	.70000+10	.14286-01
14	03/10/70	.70000+08	.90000+10	.77778-02



BACTERIAL ADSORPTION EXPERIMENTS - LANGMUIR ISOTHERM

RUNS	2	SORBENT	MENDON SILT LOAM	COMPETITIVE EXPERIMENTS
TO	14	SORBATE	STAPH-AUREUS	BACTO PEPTONE .0 GM/L
TEMP	37.000			SODIUM CHLORIDE 3.0 GM/L
				SODIUM LAURYL SULFATE .0 GM/L



BACTERIAL ADSORPTION EXPERIMENTS - LINEARIZED LANGMUIR ISOTHE

RUNS	2	SORBENT	MENDON SILT LOAM
TO	14	SORBATE	STAPH-AUREUS
TEMP	37.000		

COMPETITIVE EXPERIMENTS

BACTO PEPTONE .0 GM/L

SODIUM CHLORIDE .30 GM/L

SODIUM LAURYL SULFATE .0 GM/L

Appendix M

Soil Analysis - - Mendon Silt Loam[1]

UTAH STATE UNIVERSITY · LOGAN, UTAH 84321
AGRICULTURAL EXPERIMENT STATION
COOPERATIVE EXTENSION SERVICE

SOILS LABORATORY

February 11, 1970

D. R. Khairnar
Utah Water Research Laboratory
Campus

Soil Sample

Lab. No.	CEC(me/100g)	EC_e (mmhos)	(Exchangeable-me/100g) Na	K	Ca	Mg	OM(%)	pH
U70-31	26.7	1.0	.24	.61	40.0	9.0	4.4	7.4

Mechanical Analysis (hydrometer) →	Sand 2-.05 %	Silt .05-.002 %	Clay .005 %	Texture
	21	57	22	Silt Loam

[1] Sample obtained after air drying and sieving a sample of Mendon Silt Loam; the samples used in experiments, and reported above, is for the selected portion removed by sieve (0.991 mm).

VITA

Deorao R. Khairnar

Candidate for the Degree of

Doctor of Philosophy

Dissertation: The Effect of Chemical Competition on Thermodynamics of Bacterial Adsorption

Major Field: Soil Science

Biographical Information:

Personal Data: Born at Kalwadi, India, August 1, 1942, son of Rupa V. and Babu R. Khairnar; single.

Education: Attended elementary school in Kalwadi, India; graduated from M. Gandhi High School, Malegaon, India, in 1960; received the Bachelor of Science degree from University of Poona (India) in 1964 with a major in agriculture; received Master of Science degree from Utah State University in 1968; completed requirements for the PhD degree in Soil Science at Utah State University, in 1970.

Professional Experience: April 1968 to present, Research Associate, Utah Water Research Laboratory, Utah State University; January 1965 to April 1968, Research Assistant, Department of Soils and Meteorology, Utah State University; summer jobs held during undergraduate years include farm manager and assistant at a printing press, also during 1967 summer worked in soil testing laboratory at University of California, Davis; July 1964 to November 1964, Phytosanitary Inspector, Department of Entomology, University of Poona (India); Undergone Junior N. C. C. training in high school and senior N. C. C. training during college years.